

STANDARD LEVEL



ANSWERS

PEARSON BACCALAUREATE

STANDARD LEVEL

Chemistry

2nd Edition

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Supporting every learner across the IB continuum

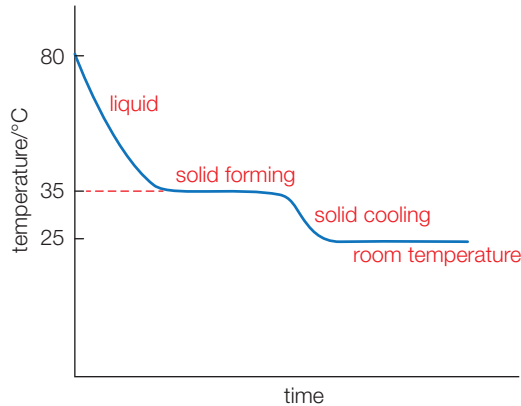
ALWAYS LEARNING

PEARSON

Answers

Chapter 1

Exercises

- 1 (a) $\text{CuCO}_3 \rightarrow \text{CuO} + \text{CO}_2$
(b) $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
(c) $\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$
(d) $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$
(e) $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- 2 (a) $2\text{K} + 2\text{H}_2\text{O} \rightarrow 2\text{KOH} + \text{H}_2$
(b) $\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$
(c) $\text{Cl}_2 + 2\text{KI} \rightarrow 2\text{KCl} + \text{I}_2$
(d) $4\text{CrO}_3 \rightarrow 2\text{Cr}_2\text{O}_3 + 3\text{O}_2$
(e) $\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 3\text{CO} + 2\text{Fe}$
- 3 (a) $2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O}$
(b) $4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O}$
(c) $3\text{Cu} + 8\text{HNO}_3 \rightarrow 3\text{Cu}(\text{NO}_3)_2 + 2\text{NO} + 4\text{H}_2\text{O}$
(d) $6\text{H}_2\text{O}_2 + 2\text{N}_2\text{H}_4 \rightarrow 2\text{N}_2 + 10\text{H}_2\text{O} + \text{O}_2$
(e) $4\text{C}_2\text{H}_7\text{N} + 15\text{O}_2 \rightarrow 8\text{CO}_2 + 14\text{H}_2\text{O} + 2\text{N}_2$
- 4 (a) Sand and water: heterogeneous
(b) Smoke: heterogeneous
(c) Sugar and water: homogeneous
(d) Salt and iron filings: heterogeneous
(e) Ethanol and water: homogeneous
(f) Steel: homogeneous
- 5 (a) $2\text{KNO}_3(\text{s}) \rightarrow 2\text{KNO}_2(\text{s}) + \text{O}_2(\text{g})$
(b) $\text{CaCO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
(c) $2\text{Li}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{LiOH}(\text{aq}) + \text{H}_2(\text{g})$
(d) $\text{Pb}(\text{NO}_3)_2(\text{aq}) + 2\text{NaCl}(\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + 2\text{NaNO}_3(\text{aq})$
(e) $2\text{C}_3\text{H}_6(\text{g}) + 9\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$
- 6 X has diffused more quickly, so it must be a lighter gas. Its particles have greater velocity than the particles of Y at the same temperature. (Note though that they will both have the same value for average kinetic energy.)
- 7 From the kinetic molecular theory we would expect a solid to be more dense than its liquid, and therefore that ice would sink in water.
- 8 Bubbles will be present through the volume of the liquid. A brown gas is visible above the brown liquid. As the two states are at the same temperature, the particles have the same average kinetic energy and are moving at the same speed. The inter-particle distances in the gas are significantly larger than those in the liquid.
- 9 At certain conditions of low temperature and low humidity, snow changes directly to water vapour by sublimation, without going through the liquid phase.
- 10 Steam will condense on the skin, releasing energy as it forms liquid at the same temperature (e–d on Figure 1.4). This is additional to the energy released when both the boiling water and the condensed steam cool on the surface of the skin.
- 11 B
- 12
- 
- 13 These calculations have used $L = 6.02 \times 10^{23}$
(a) 7.2×10^{22} (b) 3.01×10^{24}
(c) 1.2×10^{23}
- 14 0.53 mol H
- 15 0.250 mol

- 16 (a) 262.87 g mol⁻¹ (b) 176.14 g mol⁻¹
(c) 164.10 g mol⁻¹ (d) 248.22 g mol⁻¹
- 17 189.1 g
- 18 1.5 mol
- 19 0.0074 mol Cl⁻
- 20 1.83×10^{24} C atoms
- 21 171 g (integer value because no calculator)
- 22 10.0 g H₂O
- 23 2.0 mol N₂ > 3.0 mol NH₃ > 25.0 mol H₂ > 1.0 mol N₂H₄
- 24 (a) CH (b) CH₂O
(c) C₁₂H₂₂O₁₁ (d) C₄H₉
(e) C₄H₇ (f) CH₂O
- 25 Na₂S₂O₃
- 26 CoSO₄·7H₂O
- 27 C₁₇H₂₅N
- 28 NH₃
- 29 6.94 Li
- 30 CdS
- 31 empirical formula CH; molecular formula C₆H₆
- 32 empirical formula H₂PO₃; molecular formula H₄P₂O₆
- 33 C₁₀H₁₆N₅P₃O₁₃ for both empirical and molecular formulas
- 34 C₃H₈O
- 35 Let y = mass of chalk in grams.
moles of chalk used = $\frac{\text{mass used}}{M_r(\text{CaCO}_3)}$
$$= \frac{y \text{ g}}{100.09 \text{ g mol}^{-1}}$$

This is the same as the number of moles of carbon atoms used.
Therefore the number of carbon atoms used
= moles of chalk × (6.02 × 10²³ mol⁻¹)
$$= \frac{6.02 \times 10^{23} y}{100.09}$$
- 36 (a) 2.50 mol (b) 5.63 mol
(c) 665.5 g
- 37 (a) 2C₄H₁₀ + 13O₂ → 8CO₂ + 10H₂O
(b) 1.59 g
- 38 4.355 kg
- 39 (a) CaCO₃ → CaO + CO₂
(b) 92.8%
(c) CaCO₃ is the only source of CO₂; all the CaCO₃ undergoes complete decomposition; all CO₂ released is captured; heating does not cause any change in the mass of the other minerals present.
- 40 (a) 85.2 g (b) 1.3 g H₂
- 41 5.23 g C₂H₄Cl₂
- 42 254 g theoretical CaSO₃; 77.9%
- 43 3.16 g ester
- 44 107 g of C₆H₆ needed
- 45 (a) 2.40 mol (b) 0.0110 mol
(c) 44 mol
- 46 (a) 35.65 dm³ (b) 5.7 dm³
- 47 0.652 dm³
- 48 0.138 mol Br₂ and 0.156 mol Cl₂, so more molecules of Cl₂
- 49 0.113 dm³
- 50 0.28 dm³
- 51 90 kPa
- 52 16 °C
- 53 3.0 dm³
- 54 2.8 dm³
- 55 $M = 133 \text{ g mol}^{-1}$ so gas is Xe
- 56 90.4 g mol⁻¹
- 57 Helium
- 58 311 dm³
- 59 empirical formula and molecular formula = SO₃

- 60 At higher altitude the external pressure is less. As the air in the tyre expands on heating (due to friction with the road surface), the internal pressure increases.
- 61 (a) Particles are in constant random motion and collide with each other and with the walls of the container in perfectly elastic collisions. The kinetic energy of the particles increases with temperature. There are no inter-particle forces and the volume of the particles is negligible relative to the volume of the gas.
- (b) At low temperature, the particles have lower kinetic energy, which favours the formation of inter-particle forces and reduces gas pressure. $\frac{PV}{nRT} < 1$
- 62 NH_3 shows greater deviation than CH_4 due to stronger intermolecular attractions, especially at low temperature.
- 63 B
- 64 2.81 g
- 65 4.93 g
- 66 0.0100 mol
- 67 $0.400 \text{ mol dm}^{-3}$
- 68 3.1 cm^3
- 69 $0.178 \text{ mol dm}^{-3}$
- 70 $0.0220 \text{ mol dm}^{-3}$, 0.0802% HCl
- 71 $0.106 \text{ mol dm}^{-3} \text{ Na}_2\text{SO}_4$ and $0.115 \text{ mol dm}^{-3} \text{ Pb}(\text{NO}_3)_2$; assume no side reactions, all PbSO_4 precipitates

Practice questions

The answers to the practice questions below are as given to the IB examiners. The following notes may help you to interpret these and make full use of the guidance given.

- There are no half marks awarded. Each mark is shown by the number in square brackets [1].

- Alternative possible answers are separated from each other by a slash (/).
- Any answer given in **bold** or underlined must be present to score the mark.
- Information in brackets () is not needed to score the mark.
- Notes given in italics are to guide the examiner on what to accept/reject in their marking.
- OWTTE means 'or words to that effect', so alternative wording that conveys the same meaning can be equally rewarded.
- ECF means 'error carried forward', so examiners must award a mark for an incorrect answer from an earlier part of a question used correctly in a subsequent step.
- M1, M2 etc. represent method marks to be awarded by an examiner for answers showing the appropriate steps of the working (method) necessary for answering the question.

You may notice occasional differences between the calculations or wordings given in the answers and those in the worked solutions. This is because the answers give the final solution with the minimum of working, and the worked solutions provide the extra reasoning and working needed to understand how the answers are attained.

- | | | | |
|------|------|------|------|
| 1 D | 2 D | 3 B | 4 C |
| 5 A | 6 B | 7 D | 8 D |
| 9 D | 10 D | 11 A | 12 C |
| 13 D | 14 C | 15 D | 16 A |

- 17 (a) temperature: 4
mass: 3
pressure: 3

[1]

- (b) $0.0650 \text{ kg} = 65.0 \text{ g}$

$$n = \frac{65.0}{65.02} = 1.00 \text{ (mol)}$$

[1]

No penalty for using whole number atomic masses.

- (c) $n(\text{N}_2) = \frac{3}{2} \times 1.00 = 1.50 \text{ (mol)}$

$$T = 25.00 + 273.15 = 298.15 \text{ K or } 25.00 + 273 = 298 \text{ K}$$

$P = 1.08 \times 1.01 \times 10^5 \text{ Pa}$ or $1.08 \times 1.01 \times 10^2 \text{ kPa}$ or $1.09 \times 10^5 \text{ Pa}$ or $1.09 \times 10^2 \text{ kPa}$

$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ (from IB Data booklet)

Use $PV = nRT$ (from IB Data booklet)

$$V = \frac{nRT}{P} = \frac{1.50 \times 8.31 \times 298.15}{1.08 \times 1.01 \times 10^5} = 0.034.1 \text{ m}^3 = 34.1 \text{ dm}^3 \quad [4]$$

Award **[4]** for correct final answer.

Award **[3]** (max) for 0.0341 dm^3 or 22.7 dm^3 .

Award **[3]** (max) for 34.4 dm^3 .

Award **[2]** (max) for 22.9 dm^3 .

Award **[2]** (max) for 0.0227 dm^3 .

Award **[2]** (max) for 0.034 dm^3 .

18 (a) $\left(\frac{2 \times 1.01}{18.02}\right)(0.089) = 1.0 \times 10^{-2} \text{ g H}$ and $\left(\frac{12.01}{44.01}\right)(0.872) = 2.38 \times 10^{-1} \text{ g C}$
 $\left(\frac{0.238}{1.30}\right)(100) = 18.3\% \text{ C}$
 $\left(\frac{1.0 \times 10^{-2}}{1.30}\right)(100) = 0.77\% \text{ H} \quad [3]$

Award **[3]** for correct final answer of 18.3% C and 0.77% H without working.
 Allow whole numbers for molar masses.

(b) $\left(1.75\right)\left(\frac{35.45}{143.32}\right) = 0.433 \text{ g (Cl)}$ and $\left(\frac{0.433}{0.535}\right)(100) = 80.9\% \text{ (Cl)} \quad [1]$

Allow whole numbers for molar masses.

(c) $\left(\frac{18.3}{12.01}\right) = 1.52 \text{ mol C}$ and $\left(\frac{0.77}{1.01}\right) = 0.76 \text{ mol H}$ and $\left(\frac{80.9}{35.45}\right) = 2.28 \text{ mol Cl}$

Allow whole numbers for atomic masses.

Empirical formula = C_2HCl_3 ;

Award **[2]** for correct empirical formula without working.

$M_r = (24.02 + 1.01 + 106.35) = 131.38$
 so molecular formula is $\text{C}_2\text{HCl}_3 \quad [3]$

Award **[3]** for correct final answer without working.

Allow whole numbers for atomic masses.

19 NH_3 /ammonia in excess, by $10 \text{ dm}^3 \quad [1]$

volume of N_2 produced = $25.0 \text{ dm}^3 \quad [2]$

20 (a) $n(\text{HCl}) = 0.200 \text{ mol dm}^{-3} \times 0.02720 \text{ dm}^3 = 0.00544$ or $5.44 \times 10^{-3} \text{ (mol)} \quad [1]$

(b) $n(\text{HCl})$ excess is $0.100 \text{ mol dm}^{-3} \times 0.02380 \text{ dm}^3 = 0.00238$ or $2.38 \times 10^{-3} \text{ mol} \quad [1]$

Penalize not dividing by 1000 once only in (a) and (b).

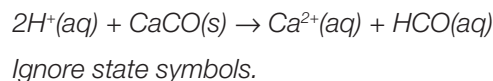
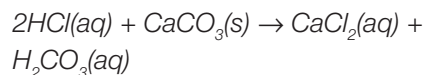
(c) $n(\text{HCl})$ reacted = $0.00544 - 0.00238 = 0.00306$ or $3.06 \times 10^{-3} \text{ (mol)} \quad [1]$

(d) $2\text{HCl(aq)} + \text{CaCO}_3(\text{s}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O(l)} + \text{CO}_2(\text{g})$ or $2\text{H}^+(\text{aq}) + \text{CaCO}_3(\text{s}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2\text{O(l)} + \text{CO}_2(\text{g}) \quad [2]$

Award **[1]** for correct reactants and products.

Award **[1]** if the equation is correctly balanced.

Award **[1]** (max) for the following equations:



(e) $n(\text{CaCO}_3) = \frac{1}{2}n(\text{HCl}) = \frac{1}{2} \times 0.00306 = 0.00153$ or $1.53 \times 10^{-3} \text{ mol} \quad [2]$

Award **[2]** for correct final answer.

(f) $M_r(\text{CaCO}_3) = 40.08 + 12.01 + 3 \times 16.00 = 100.09$ or 100.1 g mol^{-1}

Accept 100.

$$m(\text{CaCO}_3) = n \times M = 0.00153 \text{ mol} \times 100.09 \text{ g mol}^{-1} = 0.153 \text{ g}$$

$$\% \text{CaCO}_3 = \frac{0.153}{0.188} \times 100 = 81.4\% \text{ or } 81.5\% \quad [3]$$

Ignore state symbols.

Accept answers in the range 79.8% to 81.5%.

Award **[3]** for correct final answer.

(g) only CaCO_3 reacts with acid or impurities are inert or non-basic or impurities do not react

with the acid *or* nothing else in the eggshell reacts with acid *or* no other carbonates. [1]

Do not accept 'all calcium carbonate reacts with acid'.

- 21 NaCl 62.9%, CaCl₂ 37.1% [2]
- 22 (a) 0.115 mol H₂O [1]
 (b) 0.0574 mol K₂CO₃ [1]
 (c) K₂CO₃·2H₂O [1]
 (d) Heat to constant mass – when further heating does not lead to further decrease in mass. [1]
- 23 (a) NH₃ is in excess [1]
 (b) HCl is limiting [1]
 (c) 1.64 g ammonium chloride forms [1]
- 24 (a) 2PbS(s) + 3O₂(g) → 2PbO(s) + 2SO₂(g) [1]
 (b) 268 kg [2]
 (c) All the PbO reacts/O₂ is in excess.
 There are no side reactions/other products. [2]
- 25 (a) 2Al(s) + 3CuSO₄(aq) → Al₂(SO₄)₃(aq) + 3Cu(s) [1]
 (b) 6.920 mol Al(s) [1]
 (c) 3.95 mol Cu(s) [1]
 (d) The solid aluminium will seem to disappear and the pink/brown colour of copper will appear. The blue colour of the CuSO₄(aq) solution will fade. [2]

Challenge yourself

- 1 In cold climates, temperature may approach or go below the boiling point of butane so the butane stays liquid even when it is released from the pressure it is under when stored in its canister. This makes it ineffective as a fuel.
- 2 FeCl₃·6H₂O, CuSO₄·5H₂O, Co(NO₃)₂·6H₂O
- 3 N = 18%, P = 22%, K = 17%
- 4 Many reactions with 'useless' by-products could have high stoichiometric yield under optimum conditions, but low atom economy, for example methanoic acid production:
- $$2\text{NaCOOH} + \text{H}_2\text{SO}_4 \rightarrow 2\text{HCOOH} + \text{Na}_2\text{SO}_4$$
- For 100% conversion with stoichiometric reactants, the yield = 100%.
- $$\text{atom economy} = \frac{2 \times 46.03}{(2 \times 68.01) + 98.08} \times 100\% = 39.33\%$$
- 5 2NaN₃(s) → 2Na(s) + 3N₂(g)
 10Na(s) + 2KNO₃(s) → K₂O(s) + 5Na₂O(s) + N₂(g)
 K₂O(s) + Na₂O(s) + SiO₂(s) → Na₂K₂SiO₄ (alkaline silicate glass)
- 6 As NaOH dissolves, the separated Na⁺ and OH⁻ ions become hydrated, i.e. they are surrounded by H₂O molecules. This involves breaking the hydrogen bonds between the H₂O molecules in pure water and allows closer packing, which reduces the volume.

Answers

Chapter 2

Exercises

- Examples are density (related to mass) or, for gases, rate of diffusion.
- Tellurium has a greater proportion of heavier isotopes (with more neutrons).

3

	Species	No. of protons	No. of neutrons	No. of electrons
(a)	${}^7\text{Li}$	3	4	3
(b)	${}^1\text{H}$	1	0	1
(c)	${}^{14}\text{C}$	6	8	6
(d)	${}^{19}\text{F}^-$	9	10	10
(e)	${}^{56}\text{Fe}^{3+}$	26	30	23

4

	Species	No. of protons	No. of neutrons	No. of electrons
	${}^{40}\text{Ca}^{2+}$	20	20	18
(a)	${}^{40}_{18}\text{Ar}$	18	22	18
(b)	${}^{39}_{19}\text{K}^+$	19	20	18
(c)	${}^{35}_{17}\text{Cl}^-$	17	18	18

5 C

	Species	No. of protons	No. of neutrons	No. of electrons
A	${}^2_1\text{H}$	1	1	1
B	${}^{11}_5\text{B}$	5	6	5
C	${}^{16}_8\text{O}^{2-}$	8	8	10
D	${}^{19}_9\text{F}^-$	9	10	10

6 B 7 B

- 8 Let x atoms be ${}^{20}\text{Ne}$ atoms. The remaining atoms are ${}^{22}\text{Ne}$.
- number of ${}^{22}\text{Ne}$ atoms = $100 - x$
- total mass = $20 \times x + (100 - x) \times 22 = 2200 - 2x$
- average mass = $\frac{2200 - 2x}{100}$

From the Periodic Table we see that the relative atomic mass of neon = 20.18

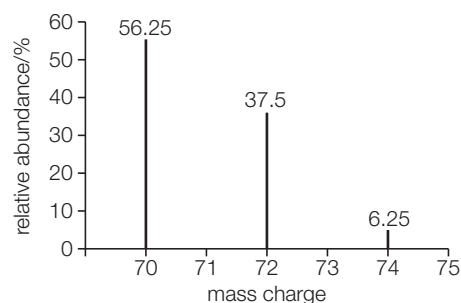
$$20.18 = \frac{2200 - 2x}{100}$$

$$2018 = 2200 - 2x$$

$$2x = 2200 - 2018 = 182$$

$$x = 91; \text{abundance } {}^{20}\text{Ne} = 91\%$$

- 9 probability of ${}^{35}\text{Cl} = \frac{3}{4}$ probability of ${}^{37}\text{Cl} = \frac{1}{4}$
- probability of ${}^{35}\text{Cl}-{}^{35}\text{Cl}$ ($M = 70$) = $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16} = 56.25\%$
- probability of ${}^{35}\text{Cl}-{}^{37}\text{Cl}/{}^{37}\text{Cl}-{}^{35}\text{Cl}$ ($M = 72$) = $2 \times \frac{3}{4} \times \frac{1}{4} = \frac{6}{16} = 37.5\%$
- probability of ${}^{37}\text{Cl}-{}^{37}\text{Cl}$ ($M = 74$) = $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16} = 6.25\%$



- 10 Let the abundance of ${}^{25}\text{Mg}$ be x . Consider 100 atoms.
- $$24.31 = \frac{(78.90 \times 24) + (x \times 25) + (100 - 78.90 - x) \times 26}{100}$$
- $$= 1893.6 + 25x + 2600 - 2051.4 - 26x$$
- $$= 2442.2 - x$$
- $$x = 11.20$$
- ${}^{25}\text{Mg}$ 11.20% and ${}^{26}\text{Mg}$ 9.90%

11 B 12 C 13 A 14 A

15 $4s < 4p < 4d < 4f$

16	Sub-level	4s	4p	4d	4f
	No. of orbitals	1	3	5	7

17 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

18 $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2 3s^2 3p_x^1 3p_y^1 3p_z^1$, so three unpaired electrons

19 C 20 C

21 (a) V is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$

(b) K is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

(c) Se is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$

(d) Sr is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^2$

22 D 23 B 24 B

25 (a) O^{2-} is $1s^2 2s^2 2p^6$

(b) Cl^- is $1s^2 2s^2 2p^6 3s^2 3p^6$

(c) Ti^{3+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1$

(d) Cu^{2+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$

	Ion	3d					4s
(a)	Ti^{2+}	↑	↑				
(b)	Fe^{2+}	↑↓	↑	↑	↑	↑	
(c)	Ni^{2+}	↑↓	↑↓	↑↓	↑	↑	
(d)	Zn^{2+}	↑↓	↑↓	↑↓	↑↓	↑↓	

27 (a) Ne is $1s^2 2s^2 2p^6$

(b) Negatively charged ions would be F^- , O^{2-} or N^{3-} ; positively charged ions would be Na^+ , Mg^{2+} or Al^{3+} .

28 (a) Cl is $1s^2 2s^2 2p^6 3s^2 3p^5$

(b) Nb is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^4 5s^2$

(c) Ge is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$

(d) Sb is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^3$

29 (a) Si (b) Mn (c) Sr (d) Sc

30 11 31 20 32 $[Kr] 4d^{10}$

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- | | | | |
|-----|------|------|-----|
| 1 D | 2 A | 3 A | 4 B |
| 5 D | 6 A | 7 C | 8 B |
| 9 B | 10 D | 11 C | |

12
$$\frac{(54 \times 5.95) + (56 \times 91.88) + (57 \times 2.17)}{100} = 55.90 \quad [2]$$

Award [2] for correct final answer.


Answer must be to 2 d.p.

13 (a) the electron configuration (of argon) or $1s^2 2s^2 2p^6 3s^2 3p^6$ [1]

(b) $x = 1$ and $y = 5$ [1]

(c)  [1]

Accept all six arrows pointing down rather than up.

14  [1]

15 (a) Cobalt has a greater proportion of heavier isotopes (OWTTE) or cobalt has a larger number of neutrons. [1]

(b) 27 protons and 25 electrons [1]

(c) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$ or $[Ar] 3d^7$ [1]

Challenge yourself

1 In 1827 Robert Brown dropped grains of pollen into water and examined them under a microscope. The pollen moved around erratically in the water. This so-called 'Brownian motion' was explained in 1905 by Albert Einstein. He realized that the pollen was being jostled by something even smaller: water molecules. Einstein didn't just base this theory on his observations – he used complex mathematics to show that an atomic model could explain Brownian motion.

2 Potash, soda, magnesia and barytes are compounds of Group 1 and 2 elements. In order to obtain the Group 1 and 2 elements (which are metals) from these compounds (which are ionic compounds) it is necessary to reduce them from their ions. This was not possible using the chemical methods available at the time and these compounds were later broken down into their component elements by electrolysis.

3 The Schrödinger model:

- does not have well-defined orbits for the electrons
- does not treat the electron as a localized particle but gives a probability wave description
- predicts the relative intensities of various spectral lines.

4 (a) $[\text{Rn}]7s^25f^{14}6d^7$

(b) The first g block element would be



$$Z = 86 + 2 + 14 + 10 + 6 + 2 + 1 = 121$$

5 $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^{14}5d^{10}6p^65f^4$

6 (a) There would be two types of p orbital and two types of d orbitals.

(b) Four groups in the p and d blocks.

Answers

Chapter 3

Exercises

- 1**
- | | Element | Period | Group |
|-----|----------|--------|-------|
| (a) | helium | 1 | 18 |
| (b) | chlorine | 3 | 17 |
| (c) | barium | 6 | 2 |
| (d) | francium | 7 | 1 |
- 2** (a) Periods are rows and groups are columns.
 (b) $1s^2 2s^2 2p^6 3s^2 3p^3$
 The valence energy level is the third principal energy level, so the element is in period 3. It has the $3p^3$ configuration, so it is in the third group of the p block, which is Group 15.
- 3** Element 51 is antimony (Sb), which is in Group 15. Its valence electrons are $5s^2 5p^3$, and so it has five valence electrons.
- 4** C **5** B **6** C
- 7** (a) Half the distance between the nuclei of neighbouring atoms of the same element.
 (b) (i) The noble gases do not form stable ions and engage in ionic bonding so the distance between neighbouring ions cannot be defined.
 (ii) The atomic radii decrease from Na to Cl. This is because the number of inner, shielding, electrons is constant (10) but the nuclear charge increases from +11 to +17. As we go from Na to Cl, the increasing effective nuclear charge pulls the outer electrons closer.
- 8** Si^{4+} has an electronic configuration of $1s^2 2s^2 2p^6$ whereas Si^{4-} has an electronic configuration of $1s^2 2s^2 2p^6 3s^2 3p^6$. Si^{4+} has two occupied energy levels and Si^{4-} has three and so Si^{4-} is larger.
- 9** A **10** B **11** C **12** D
- 13** (a) The electron in the outer electron energy level (level 4) is removed to form K^+ . The net attractive force increases as the electrons in the third energy level experience a greater effective nuclear charge.
 (b) P^{3-} has an electronic configuration of $1s^2 2s^2 2p^6 3s^2 3p^6$ whereas Si^{4+} has an electronic configuration of $1s^2 2s^2 2p^6$. P^{3-} has one more principal energy level than Si^{4+} so its valence electrons will be further from the nucleus and it will have a larger ionic radius.
 (c) The ions have the same electron configuration, $1s^2 2s^2 2p^6 3s^2 3p^6$: both have two complete shells; the extra protons in Na^+ attract the electrons more strongly.
- 14** Phosphorus exists as molecules with four atoms: P_4 . Sulfur exists as molecules with eight atoms: S_8 . There are stronger London dispersion forces between the larger S_8 molecules as there are more electrons.
- 15** D **16** C **17** $Cl^- > Cl > Cl^+$
- 18** B **19** C **20** D **21** B
- 22** Sodium floats on the surface; it melts into a sphere; there is fizzing/effervescence/bubbles; sound is produced; solution gets hot; white smoke is produced.

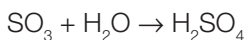
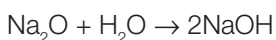
$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$
- 23** D
- 24** The reactivities of the alkali metals increase but those of the halogens decrease.
- 25** C **26** D **27** D **28** A
- 29** A **30** B **31** D

	State under standard conditions (a)	Structure and bonding (b)
MgO	(s)	giant structure ionic bonding; strong attraction between oppositely charged ions
SiO ₂ (quartz)	(s)	giant structure covalent bonding; strong covalent bonds throughout structure
P ₄ O ₁₀	(s)	molecular, covalent bonding; weak intermolecular forces between molecules; P ₄ O ₁₀ is larger molecule and so has stronger London dispersion forces and a higher melting point than SO ₂
SO ₂	(g)	molecular, covalent bonding; weak intermolecular forces between molecules; SO ₂ is smaller molecule and so has weaker London dispersion forces and a higher melting point than P ₄ O ₁₀

(c)	Oxide	pH of solution	Equations
	MgO	alkaline	$\text{MgO(s)} + \text{H}_2\text{O(l)} \rightarrow \text{Mg(OH)}_2\text{(aq)}$
	SiO ₂ (quartz)	neutral – oxide is insoluble	
	P ₄ O ₁₀	acidic	$\text{P}_4\text{O}_{10}\text{(s)} + 6\text{H}_2\text{O(l)} \rightarrow 4\text{H}_3\text{PO}_4\text{(aq)}$
	SO ₂	acidic	$\text{SO}_2\text{(l)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{SO}_3\text{(aq)}$

- (d) (i) $\text{Al}_2\text{O}_3\text{(s)} + 6\text{HCl(aq)} \rightarrow 2\text{AlCl}_3\text{(aq)} + 3\text{H}_2\text{O(l)}$
(ii) $\text{Al}_2\text{O}_3\text{(s)} + 2\text{NaOH(aq)} + 3\text{H}_2\text{O(l)} \rightarrow 2\text{NaAl(OH)}_4\text{(aq)}$

- 33 The oxides of Na and Mg are basic; the oxide of Al is amphoteric; the oxides of Si to Cl are acidic. Ar forms no oxide.



Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 C 2 A 3 B 4 B
5 A 6 B 7 C

- 8 (a) the amount of energy required to remove one (mole of) electron(s) [1]
from (one mole of) an atom(s) in the gaseous state [1]

- (b) greater positive charge on nucleus / greater number of protons / greater core charge [1]
greater attraction by Mg nucleus for electrons (in the same shell) / smaller atomic radius [1]

- 9 $\text{Na}_2\text{O(s)} + \text{H}_2\text{O(l)} \rightarrow 2\text{NaOH(aq)}$ [1]
 $\text{SO}_3\text{(l)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{SO}_4\text{(aq)}$ [1]

State symbols are not needed.

Na₂O is basic and SO₃ is acidic [1]

- 10 (a) Na: 11 p, 11/2.8.1 e⁻ and Na⁺: 11 p, 10/2.8 e⁻ OR Na⁺ has 2 shells/energy levels, Na has 3 / OWTTE [1]

Na⁺ has greater net positive charge/same number of protons pulling smaller number of electrons [1]

- (b) Si⁴⁺: 10 e⁻ in 2 (filled) energy levels / electron arrangement 2.8 / OWTTE [1]

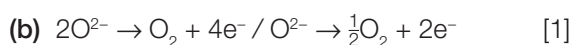
P³⁻: 18 e⁻ in 3 (filled) energy levels / electron arrangement 2.8.8, thus larger / OWTTE [1]

OR Si⁴⁺ has 2 energy levels whereas P³⁻ has 3 / P³⁻ has one more (filled) energy level [1]

Si⁴⁺ has 10 e⁻ whereas P³⁻ has 18 e⁻ / Si⁴⁺ has fewer electrons / P³⁺ has more electrons [1]

- 11 (a) in the solid state ions are in fixed positions / there are no moveable ions / OWTTE [1]

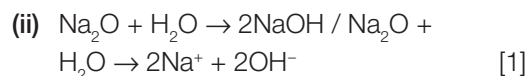
Do not accept answer that refers to atoms or molecules.



Accept e instead of e⁻.

(c) (i) basic [1]

Allow alkaline.



Do not accept \rightleftharpoons

Challenge yourself

1 Ytterbium, yttrium, terbium, erbium

2 Two liquids, 11 gases

3 Metalloids are elements that have chemical and physical properties intermediate to those of metals and non-metals, and include the elements boron, silicon, germanium, arsenic, antimony and tellurium.

Semi-conductors are materials (elements or compounds) that have electrical conductivity between those of conductors and insulators.

Some metalloids are also semi-conductors. Silicon and germanium are two examples.

4 $1\text{s}^2 2\text{s}^2 2\text{p}^6 3\text{s}^2 3\text{p}^6 4\text{s}^2 3\text{d}^{10} 4\text{p}^6 5\text{s}^2 4\text{d}^{10} 5\text{p}^6 4\text{f}^7 6\text{s}^2$ or $[\text{Xe}]4\text{f}^7 6\text{s}^2$

Answers

Chapter 4

Exercises

- 1 lead nitrate, $\text{Pb}(\text{NO}_3)_2$
barium hydroxide, $\text{Ba}(\text{OH})_2$
potassium hydrogencarbonate, KHCO_3
magnesium carbonate, MgCO_3
copper sulfate, CuSO_4
calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$
ammonium chloride, NH_4Cl
- 2 (a) KBr (b) ZnO
(c) Na_2SO_4 (d) CuBr_2
(e) $\text{Cr}_2(\text{SO}_4)_3$ (f) AlH_3
- 3 (a) tin(II) phosphate
(b) titanium(IV) sulfate
(c) manganese(II) hydrogencarbonate
(d) barium sulfate
(e) mercury sulfide
- 4 (a) Sn^{2+} (b) Ti^{4+}
(c) Mn^{2+} (d) Ba^{2+}
(e) Hg^+
- 5 A_3B_2
- 6 Mg 12: electron configuration $[\text{Ne}]3s^2$
Br 35: electron configuration $[\text{Ar}]3d^{10}4s^24p^5$
The magnesium atom loses its two electrons from the 3s orbital to form Mg^{2+} . Two bromine atoms each gain one electron into their 4p sub-shell to form Br^- . The ions attract each other by electrostatic forces and form a lattice with the empirical formula MgBr_2 .
- 7 B 8 D
- 9 Test the melting point: ionic solids have high melting points.
Test the solubility: ionic compounds usually dissolve in water but not in hexane.
Test the conductivity: ionic compounds in aqueous solution are good conductors.
- 10 D 11 C
- 12 (a) $\text{H}-\overset{\delta+}{\text{Br}}-\overset{\delta-}{\text{Br}}$ (b) $\overset{\delta-}{\text{O}}=\overset{\delta+}{\text{C}}=\overset{\delta-}{\text{O}}$
(c) $\overset{\delta+}{\text{Cl}}-\overset{\delta-}{\text{F}}$ (d) $\text{O}=\text{O}$
(e) $\text{H}-\overset{\delta+}{\text{N}}(\overset{\delta-}{\text{H}})(\overset{\delta+}{\text{H}})-\overset{\delta-}{\text{H}}$
- 13 (a) C 2.6 H 2.2 difference = 0.4
C 2.6 Cl 3.2 difference = 0.6, more polar
(b) Si 1.9 Li 1.0 difference = 0.9
Si 1.9 Cl 3.2 difference = 1.3, more polar
(c) N 3.0 Cl 3.2 difference = 0.2
N 3.0 Mg 1.3 difference = 1.7, more polar
- 14 (a) $\text{H}-\overset{\times\times}{\underset{\times\times}{\text{F}}}-\overset{\times\times}{\underset{\times\times}{\text{F}}}$ (b) $\overset{\times\times}{\underset{\times\times}{\text{F}}}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\overset{\times\times}{\underset{\times\times}{\text{F}}}$
(c) $\text{H}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\text{H}$ (d) $\overset{\times\times}{\underset{\times\times}{\text{Cl}}}-\overset{\times\times}{\underset{\times\times}{\text{P}}}-\overset{\times\times}{\underset{\times\times}{\text{Cl}}}$
(e) $\text{H}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\text{H}$ (f) $\text{H}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\overset{\times\times}{\underset{\times\times}{\text{C}}}-\text{H}$
- 15 (a) 16 (b) 24
(c) 32 (d) 8
(e) 26
- 16 $\text{H}^+ \leftarrow \overset{\times\times}{\underset{\times\times}{\text{O}}}(\text{H})-\overset{\times\times}{\underset{\times\times}{\text{H}}} \rightarrow \left[\overset{\times\times}{\underset{\times\times}{\text{H}}}(\overset{\times\times}{\underset{\times\times}{\text{O}}}(\text{H}))-\overset{\times\times}{\underset{\times\times}{\text{H}}} \right]^+$
- 17 (a) $\left[\overset{\times\times}{\underset{\times\times}{\text{O}}}(\overset{\times\times}{\underset{\times\times}{\text{N}}}(\overset{\times\times}{\underset{\times\times}{\text{O}}}))-\overset{\times\times}{\underset{\times\times}{\text{O}}} \right]^-$ (b) $\left[\overset{\times\times}{\underset{\times\times}{\text{N}}} \equiv \overset{\times\times}{\underset{\times\times}{\text{O}}} \right]^+$
(c) $\left[\overset{\times\times}{\underset{\times\times}{\text{O}}}(\overset{\times\times}{\underset{\times\times}{\text{N}}}(\overset{\times\times}{\underset{\times\times}{\text{O}}}))-\overset{\times\times}{\underset{\times\times}{\text{O}}} \right]^-$ (d) $\overset{\times\times}{\underset{\times\times}{\text{O}}}(\overset{\times\times}{\underset{\times\times}{\text{O}}}(\overset{\times\times}{\underset{\times\times}{\text{O}}}))-\overset{\times\times}{\underset{\times\times}{\text{O}}}$
(e) $\overset{\times\times}{\underset{\times\times}{\text{H}}}(\overset{\times\times}{\underset{\times\times}{\text{N}}}(\overset{\times\times}{\underset{\times\times}{\text{H}}}))-\overset{\times\times}{\underset{\times\times}{\text{H}}}$

- 18 (a) 105° bond angle, shape is bent
 (b) 109.5° bond angle, shape is tetrahedral
 (c) 180° bond angle, shape is linear
 (d) 107° bond angle, shape is trigonal pyramidal
 (e) 120° bond angle, triangular planar
 (f) 107° bond angle, trigonal pyramidal
 (g) 105° bond angle, shape is bent
- 19 (a) 120° bond angle, shape is trigonal planar
 (b) 120° bond angle, shape is trigonal planar
 (c) 180° bond angle, shape is linear
 (d) 120° bond angle, shape is bent
 (e) 105° bond angle, shape is bent
 (f) 107° bond angle, shape is trigonal pyramidal
- 20 (a) 4 (b) 3 or 4
 (c) 2 (d) 4
 (e) 3
- 21 (a) polar (b) non-polar
 (c) polar (d) non-polar
 (e) non-polar (f) polar
 (g) non-polar (h) non-polar
- 22 *cis* isomer has a net dipole moment
- 23 $\text{CO} < \text{CO}_2 < \text{CO}_3^{2-} < \text{CH}_3\text{OH}$
- 24 The N–O bonds in the nitrate(V) ion all have a bond order of 1.33 and will be longer than two bonds in nitric(V) acid, which have a bond order of 1.5 and are shorter than the N–OH bond with a bond order of 1.
- 25 Similarities: strong, high melting points, insoluble in water, non-conductors of electricity, good thermal conductors.
 Differences: diamond is stronger and more lustrous; silicon can be doped to be an electrical conductor.
- 26 Graphite and graphene have delocalized electrons that are mobile and so conduct electrical charge. In diamond all electrons are held in covalent bonds and are not mobile.
- 27 A metal B giant molecular
 C polar molecular D non-polar molecular
 E ionic compound
- 28 A
- 29 (a) London dispersion forces
 (b) H bonds, dipole–dipole, London dispersion forces
 (c) London dispersion forces
 (d) dipole–dipole, London dispersion forces
- 30 (a) C_2H_6 (b) H_2S
 (c) Cl_2 (d) HCl
- 31 B
- 32 (a) malleability, thermal conductivity, thermal stability
 (b) light, strong, forms alloys
 (c) thermal conductivity, thermal stability, non-corrosive
 (d) light, strong, non-corrosive
- 33 (i) anodizing: increasing the thickness of the surface oxide layer helps resist corrosion
 (ii) alloying: mixing Al with other metals such as Mg and Cu increases hardness and strength

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- | | | | | | | | |
|----|---|----|---|----|---|----|---|
| 1 | C | 2 | A | 3 | A | 4 | A |
| 5 | C | 6 | B | 7 | C | 8 | A |
| 9 | B | 10 | C | 11 | C | 12 | B |
| 13 | D | 14 | B | | | | |

- 15 (a) Award [2 max] for three of the following features:

Bonding

Graphite **and** C_{60} fullerene: covalent bonds **and** van der Waals'/London/dispersion forces

Diamond: covalent bonds (and van der Waals'/London/dispersion forces)

Delocalized electrons

Graphite **and** C_{60} fullerene: delocalized electrons

Diamond: no delocalized electrons

Structure

Diamond: network/giant structure / macromolecular / three-dimensional structure **and** *Graphite*: layered structure / two-dimensional structure / planar

C₆₀ fullerene: consists of molecules / spheres made of atoms arranged in hexagons/pentagons

Bond angles

Graphite: 120° **and** *Diamond*: 109°

C₆₀ fullerene: bond angles between 109–120°

Allow Graphite: *sp*² **and** *Diamond*: *sp*³.

Allow C₆₀ fullerene: *sp*² **and** *sp*³.

Number of atoms each carbon is bonded to Graphite and C₆₀ fullerene: each C atom attached to 3 others

Diamond: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms) [6 max]

- (b) (i) network/giant structure / macromolecular each Si bonded covalently to 4 oxygen atoms **and** each O atom bonded covalently to 2 Si atoms / single covalent bonds [2]

Award [1 max] for answers such as network-covalent, giant-covalent or macromolecular-covalent.

Both M1 and M2 can be scored by a suitable diagram.

- (ii) *Silicon dioxide*: strong/covalent bonds in network/giant structure/macromolecule
Carbon dioxide: weak/van der Waals' / dispersion/London forces between molecules [2]

- (c) triple (covalent) bond
one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond [2]

Award [1 max] for representation of C≡O.

Award [2] if CO shown with dative covalent bond.

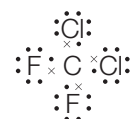
- 16 Methoxymethane is very weakly polar/weak van der Waals'/dipole-dipole forces exist between methoxymethane molecules.

Accept alternatives to van der Waals' such as London and dispersion forces

Ethanol contains a hydrogen atom bonded directly to an electronegative oxygen atom / hydrogen bonding can occur between two ethanol molecules / intermolecular hydrogen bonding in ethanol; the forces of attraction between molecules are stronger in ethanol than in methoxymethane / hydrogen bonding stronger than van der Waals'/dipole-dipole attractions. max [3]

Award [2] max if covalent bonds breaking during boiling is mentioned in the answer.

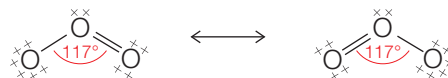
Penalize only once if no reference given to intermolecular nature of hydrogen bonding or van der Waals'.

- 17 (a)  [2]

- (b) Tetrahedral
Bond angles 109.5° [2]

- (c) Polar
C–F bond is more polar than C–Cl bond/F more electronegative than Cl and the bond dipoles do not cancel [2]

- (d) In O₃ there is more than one possible position for the double bond.



The true structure is a resonance hybrid in which the oxygen–oxygen bonds are intermediate in length and strength between single and double bonds. [3]

- (e) O₂ has double bonds and O₃ has bonds that are intermediate in strength between double and single/bond order O₂ = 2 and bond order O₃ = 1.5.

O₃ has weaker bonds than O₂.

Bonds in O₃ are broken by light of lower energy/longer wavelength than bonds in O₂. [3]

18 (a)

	Lewis (electron dot) structures	Shape of molecule	Bond angles
PH ₃		trigonal pyramidal	107°
H ₂ O		V-shaped/ bent	105°
C ₂ H ₆		tetrahedral around each C atom	109.5°
CH ₃ CHO		tetrahedral around one C atom and planar triangular around the other	109.5° 120°

[12]

- (b) H₂O can form hydrogen bonds with other H₂O molecules.

It is the only one of (i) to (iv) that contains an H atom directly bonded to O, N, or F. [2]

- 19 (a) (i) Potassium consists of a lattice of cations/K⁺ ions surrounded by a sea of delocalized electrons/mobile electrons. The bonding is non-directional. [3]

(ii)	conducts electricity	delocalized electrons are mobile and can carry charge
	conducts heat	delocalized electrons and close-packed ions enable transfer of heat energy
	malleable/ductile	non-directional nature of metallic bond means that it remains intact while conformation changes with applied pressure
	high melting point	delocalized electrons cause metallic bonds to be strong
	lustrous/shiny	delocalized electrons in crystal structure reflect light

[6]

- (b) (i) F₂(g) diatomic molecules.
Covalent bond between two F atoms.
Covalent bond is non-polar. [3]

- (ii) London (dispersion) forces between the F₂ molecules.

Instantaneous dipole-induced dipole.

Weak forces between molecules. [3]

- (c) K 1s²2s²2p⁶3s²3p⁶4s¹ and F 1s²2s²2p⁵

K loses its outer electron and forms K⁺/cation.

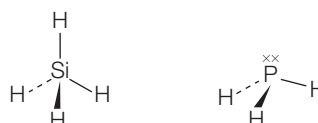
F gains electron and forms F⁻/anion.

Ions are held together by electrostatic forces of attraction in a lattice structure. [4]

- (d) Ions held tightly (by electrostatic forces)/non-mobile in solid state.

Ions can move (and carry charge) when molten or in solution. [2]

20 (a)



- (i) tetrahedral (ii) trigonal pyramidal [4]

- (b) 109.5°

Four electron domains in both SiH₄ and PH₃, but lone pair in PH₃ causes greater repulsion and decreases the angles between the H atoms. [2]

21 (a)

Trigonal pyramidal

107° [3]

- (b) Polar

Polar N–H bonds do not cancel/net dipole moment. [2]

- (c)

Tetrahedral

109.5° [3]

- (d) Coordinate covalent bond.

Lone pair on NH₃ donates to empty orbital in H⁺. [2]

- (e) NH₃ and NH₄⁺ both have four-electron domains, so are tetrahedrally arranged.

NH₃ has only three bonded electron domains

and one lone pair, which causes greater repulsion.

NH_3 bond angle is 107° and NH_4^+ bond angle is 109.5° . [3]

- 22 (a) It is not a Lewis (electron dot) structure.

All electron pairs/lone pairs of electrons are not shown. [3]

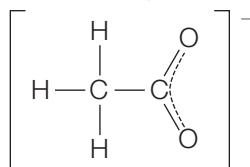
- (b) C1 bond angle: 109.5°

C2 bond angle: 120° [2]

- (c) One carbon–oxygen bond is single and the other is double. [2]

The double carbon–oxygen bond is shorter and stronger than the single bond. [2]

- (d) The true structure of the ethanoate ion is a resonance hybrid.



In this structure both carbon–oxygen bonds are equal and intermediate in length and strength between single carbon–oxygen and double carbon–oxygen bonds. [3]

- 2 F_2 has lower bond enthalpy than expected from its atomic radius due to repulsion. The bond length is so short that the lone pairs in the two atoms repel each other, weakening the bond.

- 3 When bonded to F, e.g. in OF_2

- 4 Run each solution out from separate burettes, and see whether the stream of liquid is deflected in the presence of a charged rod. Only the polar solution will show deflection.

Test solubility with ionic and covalent solutes. The polar solution will be a better solvent for polar/ionic solutes; the non-polar solution for covalent/non-polar solutes.

- 5 The high thermal conductivity of diamond is because of its strong covalent bonds. When heated the bonds becoming vibrationally excited, and as they are all connected heat energy could be readily transferred through the network from one bond to the next. Silicon is similarly a good thermal conductor – which is why computer chips need to be cooled.

- 6 Diamonds are kinetically stable with respect to graphite, as the conversion has a very high activation energy (see Chapter 6). So the reaction generally occurs too slowly to be observed.

Challenge yourself

- 1 Aluminium oxide is less ionic than MgO due to a smaller difference in electronegativity. It has some partially covalent character, which means the comparison with more ionic oxides is not fully valid.

Answers

Chapter 5

Exercises

1 B 2 B 3 A

4 D 5 C

6 $q = mc\Delta T$, so $\Delta T = \frac{q}{mc} = \frac{100}{100 \times 0.138} = 7.25\text{ }^{\circ}\text{C}$
 $T = 25.0 + 7.25 = 32.3\text{ }^{\circ}\text{C}$

7 A 8 A 9 C

10 (a) $\Delta T = 36.50 - 25.85 = 10.65\text{ }^{\circ}\text{C}$ (or K)

$$q = mc\Delta T$$

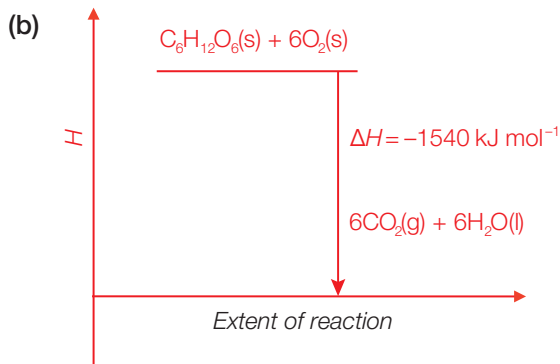
$$\begin{aligned} q &= m(\text{H}_2\text{O}) \times c(\text{H}_2\text{O}) \times \Delta T(\text{H}_2\text{O}) + m(\text{Cu}) \times \\ &\quad c(\text{Cu}) \times \Delta T(\text{Cu}) \\ &= (200.00\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times 10.65\text{ K}) + \\ &\quad (120.00\text{ g} \times 0.385\text{ J g}^{-1}\text{ K}^{-1} \times 10.65\text{ K}) \\ &= 8900\text{ J} + 492\text{ J} \end{aligned}$$

$$q = 9392\text{ J}$$

$$\begin{aligned} n(\text{C}_6\text{H}_{12}\text{O}_6) &= \frac{1.10\text{ g}}{180.18\text{ g mol}^{-1}} \\ &= 6.11 \times 10^{-3}\text{ mol} \end{aligned}$$

In calculating the enthalpy change of combustion, ΔH_c , we have to recognize that this is an exothermic reaction and that ΔH_c will therefore be a negative value.

$$\begin{aligned} \Delta H_c &= -\frac{9392\text{ J}}{6.11 \times 10^{-3}\text{ mol}} \\ &= -1.54 \times 10^6\text{ J mol}^{-1} \\ &= -1540\text{ kJ mol}^{-1} \end{aligned}$$



11 $q = mc\Delta T$

$$\begin{aligned} q &= 150.00\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times (31.5 - 25.0)\text{ K} \\ &= 4075.5\text{ J} = 4100\text{ J (to 2 s.f.)} \end{aligned}$$

$$\begin{aligned} n(\text{P}) &= \frac{0.0500\text{ g}}{30.97\text{ g mol}^{-1}} \\ &= 1.61 \times 10^{-3}\text{ mol} \end{aligned}$$

$$\begin{aligned} \Delta H_c &= \frac{-4100\text{ J}}{1.61 \times 10^{-3}\text{ mol}} \\ &= -2525 \times 10^3\text{ J mol}^{-1} \\ &= -2500\text{ kJ mol}^{-1} \end{aligned}$$

The precision of the answer is limited by the precision of measurement of the temperature difference. The value is lower than the literature value owing to heat losses and incomplete combustion.

12 $q = mc\Delta T$

$$\begin{aligned} &= 1000\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times (70.0 - 20.0)\text{ K} \\ &= 209\text{ kJ, for 1 mole of 1 mol dm}^{-3}\text{ solution} \end{aligned}$$

$$\Delta H = -209\text{ kJ mol}^{-1}$$

13 $\Delta T = 32.3 - 24.5 = 7.8\text{ K}$

$$\begin{aligned} q &= m(\text{H}_2\text{O}) \times c(\text{H}_2\text{O}) \times \Delta T(\text{H}_2\text{O}) \\ &= 100.00\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times 7.8\text{ K} \\ &= 3300\text{ J} \end{aligned}$$

$$n(\text{NaOH}) = \frac{50.00}{1000} \times 0.950 = 0.0475\text{ mol}$$

$$\begin{aligned} \Delta H &= \frac{-3300\text{ J}}{0.0475\text{ mol}} = 69 \times 10^3\text{ J mol}^{-1} \\ &= -69\text{ kJ mol}^{-1} \end{aligned}$$

Assumptions: no heat loss, $c(\text{solution}) = c(\text{water})$, $m(\text{solution}) = m(\text{H}_2\text{O})$, density(H_2O) = 1.00

14 If the mass of the solution is taken as 105.04 g (mass of water + mass of NH_2Cl dissolved), $\Delta H = +16.5\text{ kJ mol}^{-1}$.

If the mass of the solution is instead assumed to be 100.00 g (mass of water only), $\Delta H = +15.7\text{ kJ mol}^{-1}$.

$$q = mc\Delta T$$

$$\begin{aligned} &= 100.00\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times (21.79 - 25.55) \\ &= -1570\text{ J for 5.35 g} \end{aligned}$$

$$q = 293.6 \text{ J per g}$$

$$n(\text{NH}_4\text{Cl}) = 53.50 \text{ g mol}^{-1}$$

$$\Delta H = 293.6 \text{ J g}^{-1} \times 53.50 \text{ g mol}^{-1} \\ = 15.7 \text{ kJ mol}^{-1}$$

- 15 ΔH is change in enthalpy, the heat content of a system. Enthalpy cannot be measured directly but enthalpy changes can be calculated for chemical reactions and physical processes from measured temperature changes using the equation $q = mc\Delta T$, where q is the heat change, m is the mass of the substance(s) changing temperature, c is the specific heat capacity of the substance(s) changing temperature and ΔT is the measured temperature change occurring in the substance(s).

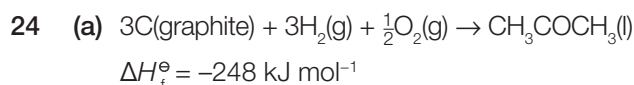
16 A

$$17 \quad \Delta H^\circ = -394 \text{ kJ} - (-283) \text{ kJ} = -111 \text{ kJ}$$

$$18 \quad \Delta H^\circ = -180.5 \text{ kJ} + (+66.4 \text{ kJ}) = -114.1 \text{ kJ}$$

$$19 \quad \Delta H^\circ = (2 \times (-33.2 \text{ kJ mol}^{-1})) + (+9.16 \text{ kJ mol}^{-1}) = -57.24 \text{ kJ mol}^{-1}$$

20 B 21 C 22 D 23 D

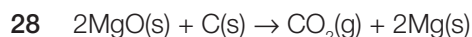


(b) Under standard conditions of 298 K (25 °C) and $1.00 \times 10^5 \text{ Pa}$. If the reaction involves solutions these have a concentration of 1.00 mol dm^{-3} .

$$25 \quad +330 \text{ kJ mol}^{-1}$$

$$26 \quad -57.2 \text{ kJ mol}^{-1}$$

27 D



$$\Delta H_{\text{reaction}}^\circ = (-394) - 2(-602) = +810 \text{ kJ mol}^{-1}$$

Such a highly endothermic reaction is unlikely to be feasible.

29 B 30 A 31 C

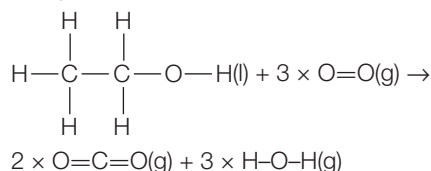
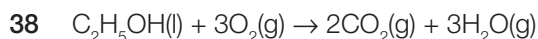
$$32 \quad 1 \times \text{C}-\text{C} + 6 \times \text{C}-\text{H}$$

33 B

$$34 \quad -125 \text{ kJ mol}^{-1}$$

$$35 \quad -486 \text{ kJ mol}^{-1}$$

36 B 37 C



Bonds broken	$\Delta H / \text{kJ mol}^{-1}$	Bonds formed	$\Delta H / \text{kJ mol}^{-1}$
C—C	+346	4 C=O	$4 \times (-804)$
3 O=O	$3 \times (+498)$	6 H—O	$6 \times (-463)$
O—H	+463		
C—O	+358		
5 C—H	$5 \times (+414)$		
Total	+4731		-5994

$$\Delta H^\circ = +4731 - 5994 \text{ kJ mol}^{-1} = -1263 \text{ kJ mol}^{-1}$$

The calculated value is less exothermic than the enthalpy of combustion in Table 13. This is because the bond enthalpy calculation assumes all species are in the gaseous state: water and ethanol are liquids.

39 (a) Step II, as bonds are formed.

(b) O_2 has a double bond. O_3 has resonance structures/delocalization with bonding intermediate between double and single bonds; the bond order is 1.5. The bonding in O_2 is stronger therefore reaction I needs more energy.

$$40 \quad L \times E_{\text{photon}} = 498 \text{ kJ} = 498000 \text{ J}$$

$$E_{\text{photon}} = \frac{498000}{6.02 \times 10^{23}} \text{ J} (= 8.272 \times 10^{-19} \text{ J})$$

$$\lambda = hc/E_{\text{photon}} \\ = 6.63 \times 10^{-34} \times 3.00 \times 10^8 \times \frac{6.02 \times 10^{23}}{498000} \\ = 2.41 \times 10^{-7} \text{ m} \\ = 241 \text{ nm}$$

Any radiation in the UV region with a wavelength shorter than 241 nm breaks the O=O bond in oxygen.

41 The oxygen double bond is stronger than the 1.5 bond in ozone. Thus, less energy is required

to dissociate O_3 than O_2 . Longer wavelength radiation of lower energy is needed to dissociate O_3 .

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 D 2 D 3 A 4 C

5 B 6 C 7 B 8 B

- 9 (a) amount of energy required to break bonds of reactants

$$3 \times 414 + 358 + 463 + 1.5 \times 498 \text{ (kJ mol}^{-1}\text{)} \\ = 2810 \text{ (kJ mol}^{-1}\text{)} \quad [1]$$

amount of energy released during bond formation of products

$$4 \times 463 + 2 \times 804 \text{ (kJ mol}^{-1}\text{)} = 3460 \text{ (kJ mol}^{-1}\text{)} \quad [1]$$

$$\Delta H = 2810 - 3460 = -650 \text{ (kJ mol}^{-1}\text{)} \quad [1]$$

Award [3] for correct final answer. Award [2] for (+)650.

- (b) (i) $m(\text{methanol}) = 80.557 - 80.034 = 0.523 \text{ (g)}$ [1]

$$n(\text{methanol}) = \frac{0.523 \text{ g}}{32.05 \text{ g mol}^{-1}} \\ = 0.0163 \text{ (mol)} \quad [1]$$

Award [2] for correct final answer.

- (ii) $\Delta T = 26.4 - 21.5 = 4.9 \text{ (K)}$ [1]

$$q = (mc\Delta T) = 20.000 \times 4.18 \times 4.9 \text{ (J)} \text{ or } \\ 20.000 \times 4.18 \times 4.9 \times 10^{-3} \text{ (kJ)} \quad [1]$$

$$= 410 \text{ J or } 0.41 \text{ kJ} \quad [1]$$

Award [3] for correct final answer.

- (iii) $\Delta H_c^\ominus = -\frac{410 \text{ (J)}}{0.0163 \text{ (mol)}} \text{ or } \\ -\frac{0.41 \text{ (kJ)}}{0.0163 \text{ (mol)}} \quad [1]$

$$= -25153 \text{ J mol}^{-1} \text{ or } -25 \text{ kJ mol}^{-1} \quad [1]$$

Award [2] for correct final answer. Award [1] for (+)25 (kJ mol⁻¹).

- (c) (i) bond enthalpies are average values/ differ (slightly) from one compound to another (depending on the neighbouring atoms) / methanol is liquid not gas in the reaction [1]

- (ii) not all heat produced transferred to water / heat lost to surroundings/ environment / OWTTE / incomplete combustion (of methanol) / water forms as $H_2O(l)$ instead of $H_2O(g)$ [Do not allow just 'heat is lost'] [1]

- 10 (a) all heat is transferred to water/copper sulfate solution / no heat loss;

specific heat capacity of zinc is zero/ negligible / no heat is absorbed by the zinc;

density of water/solution = 1.0 / density of solution = density of water;

heat capacity of cup is zero / no heat is absorbed by the cup;

specific heat capacity of solution = specific heat capacity of water;

temperature uniform throughout solution;

Award [1] each for any two. Accept

'energy' instead of 'heat' [2]

- (b) (i) $T_{\text{final}} = 73.0 \text{ (}^\circ\text{C)}$ [1]

Allow in the range 72 to 74 (°C).

$$\Delta T = 48.2 \text{ (}^\circ\text{C)} \quad [1]$$

Allow in the range 47 to 49 (°C). Award

[2] for correct final answer. Allow ECF if

T_{final} or T_{initial} correct.

- (ii) temperature decreases at uniform rate (when above room temperature) / OWTTE [1]

- (iii) 10.1 (kJ) [1]

Allow in the range 9.9 to 10.2 (kJ).

- (c) Complete colour change shows all the copper has reacted, so $n(\text{Zn}) = n(\text{CuSO}_4)$
$$= \frac{1.00 \times 50.0}{1000} = 0.0500 \text{ (mol)} \quad [1]$$

- (d) -201 kJ mol^{-1} [1]

Allow in the range -197 to $-206 \text{ (kJ mol}^{-1}\text{)}.$

Value must be negative to award mark.

11 (a) energy required = C=C + H—H
 $= 614 + 436 = 1050$
 energy released = C—C + 2(C—H)
 $= 346 + 2(414) = 1174$ [1]

Allow full consideration of breaking all bonds and forming all the new bonds, which gives values of 2706 and 2830.

energy required = C=C + H—H + 4(C—H)/612 + 436 + 4(413)

and

energy released = C—C + 6(C—H)/347 + 6(413);

$\Delta H = (1050 - 1174)$ or $(2706 - 2830) = -124 \text{ kJ mol}^{-1}$ [1]

(b) $\Delta H = -1411 + (-286) - (-1560) = -137 \text{ kJ mol}^{-1}$ [1]

(c) the actual values for the specific bonds may be different to the average values / the combustion values referred to the specific compounds / OWTTE [1]

(d) (i) -124 kJ mol^{-1} [1]

(ii) average bond enthalpies do not apply to the liquid state / OWTTE; [1]
 the enthalpy of vaporization/
 condensation of cyclohexene and
 cyclohexane / OWTTE [2]

12 bonds broken: $4 \times \text{N—H}$, $1 \times \text{N—N}$, $1 \times \text{O=O}$
 $= +2220 \text{ (kJ mol}^{-1}\text{)}$ [1]

bonds formed: $1 \times \text{N}\equiv\text{N}$, $4 \times \text{O—H} = -2797 \text{ (kJ mol}^{-1}\text{)}$ [1]

enthalpy change = $2797 + 2220 = -577 \text{ kJ mol}^{-1}$ [1]

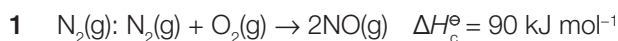
Award [3] for correct final answer.

13 reaction II (requires a shorter wavelength) [1]

O₂ has double bond/bond order 2 and O₃ intermediate between double and single bonds/bond order of $1\frac{1}{2}$ [1]

Do not accept stronger/weaker bonding without justification for the second marking point.

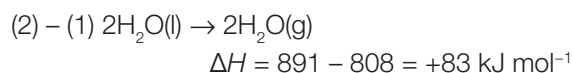
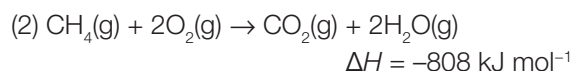
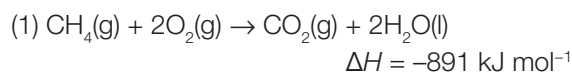
Challenge yourself



2 The specific heat capacities depend on the number of atoms in the unit mass. So c is approximately inversely proportional to the relative atomic mass.

3 The temperature of the Bunsen flame is 5748 °C

4 The difference in the values is largely due to the assumption that H₂O is gaseous in the bond enthalpy calculation (1), whereas it is actually formed as a liquid in combustion reactions (2).



There are (on average) two hydrogen bonds between each molecule so a hydrogen bond is approximately 20 kJ mol⁻¹.

This assumes that all other molecular interactions such as dipole–dipole and London dispersion forces are negligible, which is an approximation.

5 Within the sheets of graphite the C=C bond order is 1.33 and the coordination number is 3, and there are weak intermolecular forces between the layers. In diamond each carbon is bonded to four other atoms by single covalent bonds and the C—C bond order is 1. The total bonding is slightly stronger in graphite (higher bond orders) and this makes it more stable.

6 It has two unpaired electrons in the 2p sub-level.

Answers

Chapter 6

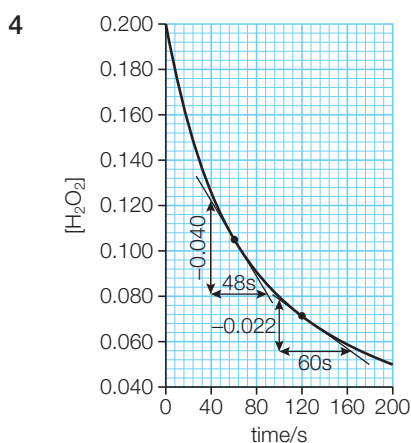
Exercises

- 1 Reaction gives off a gas: change in volume could be measured. Reaction involves purple MnO_4^- ions being reduced to colourless Mn^{2+} ions: colorimetry could be used. Reaction involves a change in the concentration of ions (23 on the reactants side and 2 on the products side): conductivity could be used.

All these techniques enable continuous measurements to be made from which graphs could be plotted of the measured variable against time.

2 C

- 3 (a) (i) Measure the decrease in the mass of flask + contents.
(ii) Measure the increase in pH of the reaction mixture.
(iii) Measure the increase in volume of gas collected.
(b) The rate of the reaction decreases with time because the concentration of the acid decreases.



At 60 s, rate = $8.3 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$

At 120 s, rate = $3.7 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$

5 D

6 A

- 7 The reaction requiring the simultaneous collision of two particles is faster. The simultaneous collision of three particles is statistically less likely.

8 B 9 B 10 B

- 11 The ashes must contain a catalyst that speeds up the reaction between sugar and oxygen. (Deduced from the fact that all other factors that affect reaction rate can be ruled out.)

- 12 (a) $2\text{CO(g)} + 2\text{NO(g)} \rightarrow 2\text{CO}_2\text{(g)} + \text{N}_2\text{(g)}$

- (b) CO is a toxic gas: it combines with haemoglobin in the blood and prevents it from carrying oxygen. NO is a primary air pollutant: it is oxidized in the air to form acidic oxides, leading to acid rain. It also reacts with other pollutants in the atmosphere, forming smog.
(c) The increased surface area of the catalyst in contact with exhaust gases will increase catalyst efficiency.
(d) Catalytic activity involves the catalyst interacting with the gases, and the reaction occurring on its surface. As temperature increases, the increased kinetic energy of the gases increases the frequency with which they bind to the catalyst.
(e) Catalytic converters reduce pollution from cars but do not remove it completely. As in (d), they are not effective when the engine first starts from cold, when an estimated 80% of pollution occurs. Other pollutants in car exhausts are not removed by the catalyst, e.g. ozone, sulfur oxides and particulates. Also the catalytic converter increases the output of CO_2 , a serious pollutant because of its greenhouse gas properties.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 B 2 A 3 C 4 C
 5 B 6 C 7 C 8 A
 9 C 10 D 11 B 12 D
- 13 A 14 B
- 15 (a) $\text{ZnCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{ZnCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ [2]
 (b) CO_2 is produced and escapes in an open system. [1]
 (c) The rate of reaction is greatest at the start and decreases with time.
 The concentration of acid decreases as it reacts and so collisions between reactants become less frequent.
 The rate approaches zero as the limiting reactant is used up. [3]
 (d) Draw a tangent to curve A and curve B at $t = 0$.
 Measure the gradient of each tangent.
 Curve A has higher gradient than curve B. [3]
 (e) A at a higher temperature than B.
 Catalyst used in A but not in B.
 The $\text{ZnCO}_3(\text{s})$ in A was in smaller pieces than in B. [3]
 (f) Higher temperature increases the frequency of collisions involving particles with $\text{KE} > E_a$.
 A catalyst provides an alternate reaction route with lower E_a .
 Smaller particle size/greater surface area leads to higher frequency of collisions between reactants. [6]

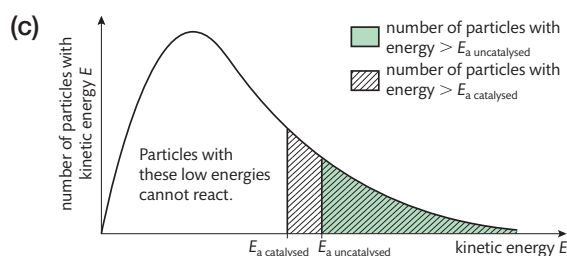
- (g) The change in mass would be much less as $\text{H}_2(\text{g})$ is lighter than $\text{CO}_2(\text{g})$.

Not satisfactory as the change in mass as the reaction proceeds is too small to measure accurately. [2]

- 16 (a) $T_2 > T_1$ [1]

- (b) At higher temperature a greater proportion of particles have higher values of KE.

Curve is shifted to the right. [2]



With a catalyst a greater proportion of particles have $\text{KE} > E_a$ and can react. [4]

- (d) (i) Enthalpy change, ΔH , depends on the difference in energy between reactants and products.
 ΔH not affected by the rate of reaction/activation energy. [4]
 (ii) The stoichiometric yield depends on the conversion of reactants to products/equilibrium position.
 Yield does not depend on rate of reaction. [4]

Challenge yourself

- 1 Collecting a gas over warm water will cause its temperature and therefore its volume to increase.

Answers

Chapter 7

Exercises

- 1 A 2 C 3 B
- 4 (a) $K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]}$ (b) $K_c = \frac{[\text{NO}_2]^4[\text{H}_2\text{O}]^6}{[\text{NH}_3]^4[\text{O}_2]^7}$
- (c) $K_c = \frac{[\text{CH}_3\text{OH}][\text{Cl}^-]}{[\text{CH}_3\text{Cl}][\text{OH}^-]}$
- 5 (a) $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$
 (b) $\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$
- 6 (a) $3\text{F}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2\text{ClF}_3(\text{g})$
 $K_c = \frac{[\text{ClF}_3]^2}{[\text{F}_2]^3[\text{Cl}_2]}$
 (b) $2\text{NO}(\text{g}) \rightleftharpoons \text{N}_2(\text{g}) + \text{O}_2(\text{g})$
 $K_c = \frac{[\text{N}_2][\text{O}_2]}{[\text{NO}]^2}$
 (c) $\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$
 $K_c = \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]}$
- 7 (a) Mostly reactants (b) Mostly reactants
 (c) Mostly products
- 8 (a) $\frac{[\text{HOCl}]^2}{[\text{H}_2\text{O}][\text{Cl}_2\text{O}]} > K$; not at equilibrium; reaction proceeds to the left
 (b) At equilibrium
 (c) $\frac{[\text{HOCl}]^2}{[\text{H}_2\text{O}][\text{Cl}_2\text{O}]} > K$; not at equilibrium; reaction proceeds to the left
- 9 (a) 7.73×10^4 (b) 3.60×10^{-3}
 (c) 6.00×10^{-2}
- 10 B 11 D 12 C
- 13 (a) Shift to the left (b) Shift to the right
 (c) No shift in equilibrium
- 14 (a) Shift to the left (b) Shift to the right
 (c) This is equivalent to an increase in pressure, so shifts to the left
 (d) Shift to the right (e) Shift to the right
- 15 (a) Amount of CO will decrease

- (b) Amount of CO will decrease
 (c) Amount of CO will increase
 (d) No change in CO

16 C 17 B

- 18 The Haber process is exothermic in the forward direction. Therefore, increasing temperature will decrease the value of K_c . This represents a decrease in the reaction yield.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 C 2 D 3 D 4 A
 5 C 6 D 7 A 8 D

9 (a) $(K =) [\text{SO}_3]^2/[\text{O}_2][\text{SO}_2]^2$ [1]

- (b) yield (of SO_3) increases / equilibrium moves to right / more SO_3 formed;

3 gaseous molecules \rightarrow 2 gaseous molecules / decrease in volume of gaseous molecules / fewer gaseous molecules on right hand side [2]

Do not allow ECF.

- (c) yield (of SO_3) decreases;

forward reaction is exothermic / reverse/backwards reaction is endothermic / equilibrium shifts to absorb (some of) the heat [2]

Do not accept exothermic reaction or Le Châtelier's principle.

Do not allow ECF.

- (d) rates of both forward and reverse reactions increase equally; no effect on position of equilibrium; no effect on value of K_c [3]

- 10 (a) reactants and products in same phase/state;
rate of forward reaction = rate of reverse reaction;
concentrations of reactants and products remain constant / macroscopic properties remain constant [2 max]
Do not accept concentrations are equal.
- (b) $K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$ [1]
- (c) no change to position of equilibrium [1]
- (d) the reaction is exothermic / heat is given out / ΔH is negative [1]
- (e) no effect (on the value of the equilibrium constant)
as it speeds up forward and reverse reaction / concentrations of reactants and products do not change / position of equilibrium does not change / no change in yield [2]

This is largely because of the size of the atoms. As I has a larger atomic radius than Cl, in HI the bonding pair is further from the nucleus than the bonding pair in HCl, and so experiences a weaker pull. The HI bond breaks more easily and so the dissociation reaction is favoured.

- 3 The concentration of a pure solid or pure liquid is a constant, effectively its density, which is independent of its amount. These constant values therefore do not form part of the equilibrium expression.
- 4 The value for K_c at 298 K for the reaction $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g})$ is extremely low, so the equilibrium mixture lies to the left with almost no production of NO. But at higher temperatures, such as in vehicle exhaust fumes, the reaction shifts to the right and a higher concentration of NO is produced. This gas is easily oxidized in the air, producing the brown gas NO_2 which is responsible for the brownish haze: $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$.
- 5 The atom economies of the Haber process and the Contact process reactions described are both 100% as there is only one product. In other words, there is no waste. But this does not mean that all reactants are converted to product, so the stoichiometric yield is less than 100%. It is the goal of these industries to maximize yield and efficiency by choosing the optimum conditions, taking equilibrium and kinetic considerations into account.

Challenge yourself

- 1 Earth receives energy from the Sun and disperses energy, largely as heat. But exchange of matter is minimal – the only exceptions to Earth being a closed system are matter received from space such as asteroids and space dust, and matter lost to space such as spacecraft.
- 2 The different values of K_c indicate different stabilities of the hydrogen halides. The bonding in HCl is the strongest and in HI the weakest.

Answers

Chapter 8

Exercises

- 1 (a) HSO_3^- (b) CH_3NH_3^+
(c) $\text{C}_2\text{H}_5\text{COOH}$ (d) HNO_3
(e) HF (f) H_2SO_4
- 2 (a) H_2PO_4^- (b) CH_3COO^-
(c) HSO_3^- (d) SO_4^{2-}
(e) O^{2-} (f) Br^-
- 3 (a) CH_3COOH (acid)/ CH_3COO^- (base)
 NH_3 (base)/ NH_4^+ (acid)
(b) CO_3^{2-} (base)/ HCO_3^- (acid)
 H_3O^+ (acid)/ H_2O (base)
(c) NH_4^+ (acid)/ NH_3 (base)
 NO_2^- (base)/ HNO_2 (acid)
- 4 $\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{PO}_4^{3-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ (acid behaviour)
 $\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{PO}_4^-(\text{aq}) + \text{OH}^-(\text{aq})$ (base behaviour)
- 5 (a) $\text{H}_2\text{SO}_4(\text{aq}) + \text{CuO}(\text{s}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$
(b) $\text{HNO}_3(\text{aq}) + \text{NaHCO}_3(\text{s}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
(c) $\text{H}_3\text{PO}_4(\text{aq}) + 3\text{KOH}(\text{aq}) \rightarrow \text{K}_3\text{PO}_4(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$
(d) $6\text{CH}_3\text{COOH}(\text{aq}) + 2\text{Al}(\text{s}) \rightarrow 2\text{Al}(\text{CH}_3\text{COO})_3(\text{aq}) + 3\text{H}_2(\text{g})$
- 6 B 7 B
- 8 (a) nitric acid + sodium carbonate / sodium hydrogencarbonate / sodium hydroxide
 $2\text{HNO}_3(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
(b) hydrochloric acid + ammonia solution
 $\text{HCl}(\text{aq}) + \text{NH}_4\text{OH}(\text{aq}) \rightarrow \text{NH}_4\text{Cl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
(c) copper(II) oxide + sulfuric acid
 $\text{H}_2\text{SO}_4(\text{aq}) + \text{CuO}(\text{s}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$
(d) methanoic acid + potassium hydroxide
 $\text{HCOOH}(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{KCOOH}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- 9 pH increases by 1 unit
- 10 pH = 4.72
- 11 $[\text{H}^+] = 1.0 \times 10^{-9} \text{ mol dm}^{-3}$, $[\text{OH}^-] = 1.0 \times 10^{-5} \text{ mol dm}^{-3}$
- 12 (a) $[\text{OH}^-] = 2.9 \times 10^{-6} \text{ mol dm}^{-3}$; basic
(b) $[\text{H}^+] = 1.0 \times 10^{-12} \text{ mol dm}^{-3}$; basic
(c) $[\text{H}^+] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$; acidic
(d) $[\text{OH}^-] = 1.2 \times 10^{-10} \text{ mol dm}^{-3}$; acidic
- 13 pH = 2.0
- 14 (a) pH = 6.9 (b) pH = 2
(c) pH = 4.8
- 15 pH = 13.17
- 16 B 17 A
- 18 (a) H_2CO_3 (b) HCOOH
- 19 (a) Contains dissolved carbon dioxide which reacts with water to form carbonic acid:
 $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
(b) Sulfuric acid:
 $\text{S}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{SO}_2(\text{g})$
 $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$
 $\text{H}_2\text{O}(\text{l}) + \text{SO}_3(\text{g}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$
(c) Nitric acid:
reduced by use of catalytic converters, recirculation of exhaust gases
(d) $\text{CaCO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
(e) Effects on materials, plant life and human health (see text for details).
(f) Use alternative energy source to fossil fuels or use coal with a low sulfur content.
- 20 (a) SO_2 and NO
(b) SO_2 and particulates

- (c) Particulates act as catalysts in the production of secondary pollutants.
- (d) $\text{SO}_2(\text{g}) + \text{CaO}(\text{s}) \rightarrow \text{CaSO}_3(\text{g})$
- (e) NO: formed from the combination of nitrogen and oxygen at the high temperature of internal combustion engines.

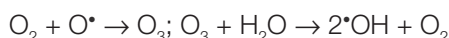
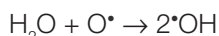
- 21 (a) Dry acid deposition typically occurs close to the source of emission.

Wet acid deposition is dispersed over a much larger area and distance from the emission source.

- (b) The acid is formed in the air from sulfur dioxide (SO_2) and nitrogen oxide (NO) which are emitted by thermal power stations, industry and motor vehicles. A major source is the burning of fossil fuels, particularly in coal-fired power stations. Pollutants are carried by prevailing winds and converted (oxidized) into sulfuric acid (H_2SO_4) and nitric acid (HNO_3). These are then dissolved in cloud droplets (rain, snow, mist, hail) and this precipitation may fall to the ground as dilute forms of sulfuric acid and nitric acid. The dissolved acids consist of sulfate ions, nitrate ions and hydrogen ions.

- 22 The hydroxyl free radical $\cdot\text{OH}$.

It is formed by the reaction between water and either ozone or atomic oxygen:



Practice questions

For advice on how to interpret the marking below please see Chapter 1.

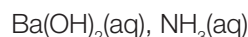
- | | | | |
|-----|------|------|------|
| 1 C | 2 D | 3 B | 4 A |
| 5 A | 6 C | 7 D | 8 B |
| 9 B | 10 B | 11 A | 12 D |

- 13 (a) Use a pH meter.

Use a suitable indicator.

[2]

- (b) $\text{HCOOH}(\text{aq})$, $\text{KCl}(\text{aq})$, $\text{HNO}_3(\text{aq})$,
pH 5 7 1



pH 13 10 [3]

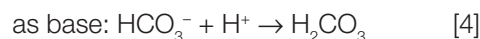
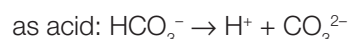
- (c) (i) $2\text{NaHCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{Na}_2\text{CO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

effervescence

solid being used up

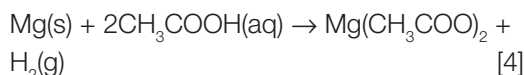
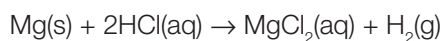
increase in temperature/exothermic reaction [5]

- (ii) HCO_3^- can act as a Bronsted–Lowry acid and base by giving and accepting protons:



- (d) Acids release $\text{H}_2(\text{g})$ when reacted with reactive metal Mg.

Reaction with strong acid more vigorous than reaction with weak acid.



- (e) Conductivity can be quantified so more objective.

The method described in (c) is qualitative only. [2]

- 14 (a) Acid: proton/ H^+ donor **and** Base: proton/ H^+ acceptor

Do not accept OH^- for base.

*Weak base: (base/electrolyte) partially dissociated/ionized (in solution/water) **and** Strong base: (base/electrolyte) assumed to be almost) completely/100% dissociated/ionized (in solution/water) / OWTTE*



Allow either name or formula or other suitable example.

- (b) sulfurous acid/ H_2SO_3

corrodes marble / limestone buildings / statues / leaching in soils / harms/kills plants

OR

nitrous acid/ HNO_2

corrodes marble / limestone buildings /
statues / leaching in soils / harms/kills plants

OR

carbonic acid/ H_2CO_3

corrodes marble / limestone buildings /
statues / acidification of lakes

[2]

Do not allow oxides (e.g. CO_2 etc.).

Do not accept just corrodes or damages.

2 Combustion of nitrogen involves the highly endothermic step ($+942 \text{ kJ mol}^{-1}$) of breaking the triple $\text{N}\equiv\text{N}$ bond, as well as the $\text{O}=\text{O}$ bond ($+498 \text{ kJ mol}^{-1}$). The exothermic step of forming the triple $\text{N}\equiv\text{O}$ bond releases less energy – approximately 630 kJ mol^{-1} . Therefore enthalpy change (*bonds broken minus bonds formed*) is endothermic. So the stability and strength of the nitrogen triple bond creates an unusual situation where the products of combustion are less stable than the reactants.

3 HNO_2 : N = +3, nitric(III) acid

HNO_3 : N = +5, nitric(V) acid

H_2SO_3 : S = +4, sulfuric(IV) acid

H_2SO_4 : S = +6, sulfuric(VI) acid

Challenge yourself

1 Sulfur is present in proteins in living cells (a component of two out of the twenty amino acids). Decomposition of plant material to peat and then coal conserves this sulfur. Additional sources are the depositional environment such as sea water, where sulfates are reduced by bacteria to form H_2S , which can react further to form organic sulfur structures.

Answers

Chapter 9

Exercises

- 1 (a) $\text{NH}_4^+ = \text{N } -3, \text{H } +1$
 (b) $\text{CuCl}_2 = \text{Cu } +2, \text{Cl } -1$
 (c) $\text{H}_2\text{O} = \text{H } +1, \text{O } -2$
 (d) $\text{SO}_2 = \text{S } +4, \text{O } -2$
 (e) $\text{Fe}_2\text{O}_3 = \text{Fe } +3, \text{O } -2$
 (f) $\text{NO}_3^- = \text{N } +5, \text{O } -2$
 (g) $\text{MnO}_2 = \text{Mn } +4, \text{O } -2$
 (h) $\text{PO}_4^{3-} = \text{P } +5, \text{O } -2$
 (i) $\text{K}_2\text{Cr}_2\text{O}_7 = \text{K } +1, \text{Cr } +7, \text{O } -2$
 (j) $\text{MnO}_4^- = \text{Mn } +7, \text{O } -2$
- 2 (a)

$$\begin{array}{ccccccc} & & \text{reduction} & & & & \\ & & \swarrow & & \searrow & & \\ \text{Sn}^{2+}(\text{aq}) & + & 2\text{Fe}^{3+}(\text{aq}) & \rightarrow & \text{Sn}^{4+}(\text{aq}) & + & 2\text{Fe}^{2+}(\text{aq}) \\ +2 & & +3 & & +4 & & +2 \\ \nwarrow & & \nearrow & & \nwarrow & & \nearrow \\ & & \text{oxidation} & & & & \end{array}$$

 (b)

$$\begin{array}{ccccccc} & & \text{reduction} & & & & \\ & & \swarrow & & \searrow & & \\ \text{Cl}_2(\text{aq}) & + & 2\text{NaBr}(\text{aq}) & \rightarrow & \text{Br}_2(\text{aq}) & + & 2\text{NaCl}(\text{aq}) \\ 0 & & +1-1 & & 0 & & +1-1 \\ \nwarrow & & \nearrow & & \nwarrow & & \nearrow \\ & & \text{oxidation} & & & & \end{array}$$

 (c)

$$\begin{array}{ccccccc} & & \text{reduction} & & & & \\ & & \swarrow & & \searrow & & \\ 2\text{FeCl}_2(\text{aq}) & + & \text{Cl}_2(\text{aq}) & \rightarrow & 2\text{FeCl}_3(\text{aq}) \\ +2-1 & & 0 & & +3-1 \\ \nwarrow & & \nearrow & & \nwarrow & & \nearrow \\ & & \text{oxidation} & & & & \end{array}$$

 (d)

$$\begin{array}{ccccccc} & & \text{reduction} & & & & \\ & & \swarrow & & \searrow & & \\ 2\text{H}_2\text{O}(\text{l}) & + & 2\text{F}_2(\text{g}) & \rightarrow & 4\text{HF}(\text{aq}) & + & \text{O}_2(\text{g}) \\ +1-2 & & 0 & & +1-1 & & 0 \\ \nwarrow & & \nearrow & & \nwarrow & & \nearrow \\ & & \text{oxidation} & & & & \end{array}$$

 (e)

$$\begin{array}{ccccccc} & & \text{reduction} & & & & \\ & & \swarrow & & \searrow & & \\ \text{I}_2(\text{aq}) & + & \text{SO}_3^{2-}(\text{aq}) & + & \text{H}_2\text{O}(\text{l}) & \rightarrow & 2\text{I}^-(\text{aq}) & + & \text{SO}_4^{2-}(\text{aq}) & + & 2\text{H}^+(\text{aq}) \\ 0 & & +4-2 & & +1-2 & & -1 & & +6-2 & & +1 \\ \nwarrow & & \nearrow & & \nwarrow & & \nearrow & & \nwarrow & & \nearrow \\ & & \text{oxidation} & & & & & & \end{array}$$
- 3 (a) $\text{Ca}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2(\text{g})$

$$\begin{array}{cccc} 0 & +1 & +2 & 0 \end{array}$$
 oxidation: $\text{Ca}(\text{s}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2\text{e}^-$
 reduction: $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$
 (b) $2\text{Fe}^{2+}(\text{aq}) + \text{Cl}_2(\text{aq}) \rightarrow 2\text{Fe}^{3+}(\text{aq}) + 2\text{Cl}^-(\text{aq})$

$$\begin{array}{cccc} +2 & 0 & +3 & -1 \end{array}$$
 oxidation: $2\text{Fe}^{2+}(\text{aq}) \rightarrow 2\text{Fe}^{3+}(\text{aq}) + 2\text{e}^-$
 reduction: $\text{Cl}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{Cl}^-(\text{aq})$
- (c) $\text{Sn}^{2+}(\text{aq}) + 2\text{Fe}^{3+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + 2\text{Fe}^{2+}(\text{aq})$

$$\begin{array}{cccc} +2 & +3 & +4 & +2 \end{array}$$
 oxidation: $\text{Sn}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + 2\text{e}^-$
 reduction: $2\text{Fe}^{3+}(\text{aq}) + 2\text{e}^- \rightarrow 2\text{Fe}^{2+}(\text{aq})$
- (d) $\text{Cl}_2(\text{aq}) + 2\text{Br}^-(\text{aq}) \rightarrow 2\text{Cl}^-(\text{aq}) + \text{Br}_2(\text{aq})$

$$\begin{array}{cccc} 0 & -1 & -1 & 0 \end{array}$$
 oxidation: $2\text{Br}^-(\text{aq}) \rightarrow \text{Br}_2(\text{aq}) + 2\text{e}^-$
 reduction: $\text{Cl}_2(\text{aq}) + 2\text{e}^- \rightarrow 2\text{Cl}^-(\text{aq})$
- 4 (a) $\text{Zn}(\text{s}) + \text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$
 (b) $2\text{I}^-(\text{aq}) + \text{HSO}_4^-(\text{aq}) + 3\text{H}^+(\text{aq}) \rightarrow \text{I}_2(\text{aq}) + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$
 (c) $\text{NO}_3^-(\text{aq}) + 4\text{Zn}(\text{s}) + 10\text{H}^+(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq}) + 4\text{Zn}^{2+}(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$
 (d) $\text{I}_2(\text{aq}) + 5\text{OCl}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{IO}_3^-(\text{aq}) + 5\text{Cl}^-(\text{aq}) + 2\text{H}^+(\text{aq})$
 (e) $2\text{MnO}_4^-(\text{aq}) + 5\text{H}_2\text{SO}_3(\text{aq}) \rightarrow 2\text{Mn}^{2+}(\text{aq}) + 3\text{H}_2\text{O}(\text{l}) + 5\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq})$
- 5 B 6 D
- 7 (a) chromium(III) oxide (b) copper(I) chloride
 (c) nitric(V) acid (d) nitric(III) acid
 (e) lead(IV) oxide
- 8 (a) reducing agent = $\text{H}_2(\text{g})$; oxidizing agent = $\text{Cl}_2(\text{g})$
 (b) reducing agent = $\text{Al}(\text{s})$; oxidizing agent = $\text{Pb}^{2+}(\text{s})$
 (c) reducing agent = $\text{I}^-(\text{aq})$; oxidizing agent = $\text{Cl}_2(\text{aq})$
 (d) reducing agent = $\text{CH}_4(\text{g})$; oxidizing agent = $\text{O}_2(\text{g})$
- 9 (a) $\text{CuCl}_2(\text{aq}) + \text{Ag}(\text{s})$
 No reaction, Cu is a more reactive metal than Ag.
 (b) $3\text{Fe}(\text{NO}_3)_2(\text{aq}) + 2\text{Al}(\text{s}) \rightarrow 2\text{Al}(\text{NO}_3)_3(\text{aq}) + 3\text{Fe}(\text{s})$
 Al is a more reactive metal than Fe, so is able to reduce Fe^{2+} .

(c) $2\text{NaI}(\text{aq}) + \text{Br}_2(\text{aq}) \rightarrow 2\text{NaBr}(\text{aq}) + \text{I}_2(\text{aq})$
Br is a more reactive non-metal than I, so is able to oxidize I^- .

(d) $\text{KCl}(\text{aq}) + \text{I}_2(\text{aq})$
No reaction, Cl is a more reactive non-metal than I.

10 (a) $W > X > Y > Z$

(b) (i) no reaction

(ii) no reaction

11 (a) Solution changes from purple to colourless

(b) $\text{C}_2\text{O}_4^{2-}(\text{aq}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{e}^-$

(c) $\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightarrow \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$

(d) $2\text{MnO}_4^-(\text{aq}) + 16\text{H}^+(\text{aq}) + 5\text{C}_2\text{O}_4^{2-}(\text{aq}) \rightarrow 2\text{Mn}^{2+}(\text{aq}) + 8\text{H}_2\text{O}(\text{l}) + 10\text{CO}_2(\text{g})$

(e) 6.16×10^{-3} (f) 6.16×10^{-3}

(g) 24.7%

12 (a) 0.117%

(b) Solution changes from orange to green

13 (a) Zn / Zn^{2+} Fe / Fe^{2+}
anode cathode

$\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$

$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Fe}(\text{s})$

(b) Fe / Fe^{2+} Mg / Mg^{2+}
cathode anode

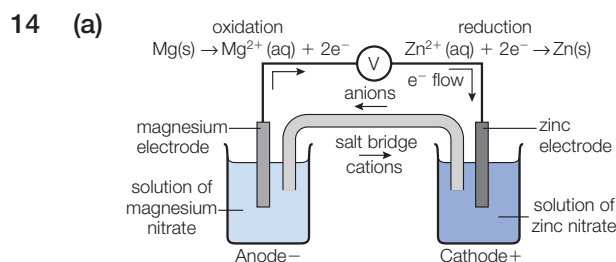
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Fe}(\text{s})$

$\text{Mg}(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$

(c) Mg / Mg^{2+} Cu / Cu^{2+}
anode cathode

$\text{Mg}(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$

$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$



(b) $\text{Mg}(\text{s}) | \text{Mg}^{2+}(\text{aq}) || \text{Zn}^{2+}(\text{aq}) | \text{Zn}(\text{s})$

15 The iron spatula would slowly dissolve as it is oxidized to Fe^{2+} ions. Copper metal would precipitate as Cu^{2+} ions are reduced. The blue colour of the solution would fade as Cu^{2+} ions are removed.

16 (a) At anode: $2\text{Br}^-(\text{l}) \rightarrow \text{Br}_2(\text{l}) + 2\text{e}^-$

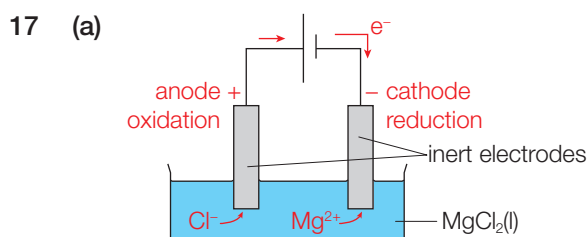
At cathode: $2\text{K}^+(\text{l}) + 2\text{e}^- \rightarrow 2\text{K}(\text{l})$

(b) At anode: $2\text{F}^-(\text{l}) \rightarrow \text{F}_2(\text{g}) + 2\text{e}^-$

At cathode: $\text{Mg}^{2+}(\text{l}) + 2\text{e}^- \rightarrow \text{Mg}(\text{l})$

(c) At anode: $\text{S}^{2-}(\text{l}) \rightarrow \text{S}(\text{l}) + 2\text{e}^-$

At cathode: $\text{Zn}^{2+}(\text{l}) + 2\text{e}^- \rightarrow \text{Zn}(\text{l})$



(b) Anode: $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$

Cathode: $\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Mg}(\text{s})$

Overall: $\text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{Mg}(\text{s}) + \text{Cl}_2(\text{g})$

18 D

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 B 2 C 3 A 4 A

5 A 6 C 7 A 8 D

9 A 10 D 11 C 12 D

13 C 14 A

15 (a) +2 [1]

(b) +3 [1]

(c) +2 [1]

Only penalize once if roman numerals are used or if written as 2+ or 3+.

16 (a) Electrolytic cell converts electrical energy to chemical energy **and** voltaic cell converts

chemical energy to electrical energy /
electrolytic cell uses electricity to carry out
a (redox) chemical reaction **and** voltaic cell
uses a (redox) chemical reaction to produce
electricity / electrolytic cell requires a power
supply **and** voltaic cell does not.

Electrolytic cell involves a non-spontaneous
(redox) reaction **and** voltaic cell involves a
spontaneous (redox) reaction.

In an electrolytic cell, cathode is negative
and anode is positive **and vice versa** for
a voltaic cell / electrolytic cell, anode is
positive and voltaic cell, anode is negative /
electrolytic cell, cathode is negative and
voltaic cell cathode is positive.

Voltaic cell has two separate solutions and
electrolytic cell has one solution / voltaic cell
has salt bridge and electrolytic cell has no
salt bridge.

Electrolytic cell, oxidation occurs at the
positive electrode/anode **and** voltaic cell,
oxidation occurs at the negative electrode/
anode and vice versa. [2 max]

- (b) (solid) ions in a lattice / ions cannot move
(molten) ions mobile / ions free to move [2]

- (c) Reduction occurs at the cathode / negative
electrode **and** oxidation occurs at the
anode / positive electrode

Cathode / negative electrode: $\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$

Anode / positive electrode: $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$
 $\text{Cl}^- \rightarrow \frac{1}{2}\text{Cl}_2 + \text{e}^-$

*Award [1 max] if the two electrodes are not
labelled/labelled incorrectly for the two half-
equations.*

Overall cell reaction: $\text{Na}^+(\text{l}) + \text{Cl}^-(\text{l}) \rightarrow$
 $\text{Na}(\text{s}) + \frac{1}{2}\text{Cl}_2(\text{g})$ [5]

*Award [1] for correct equation and [1] for
correct state symbols.*

Allow NaCl(l) instead of Na⁺(l) and Cl⁻(l).

- (d) Al does not corrode / rust; Al is less dense /
better conductor / more malleable [1]

Accept Al is lighter (metal compared to Fe).

Accept converse argument.

- 17 (a) (i) Copper: 0 to +2 / increases by
2 / +2 / 2+

Allow zero/nought for 0.

Nitrogen: +5 to +4 / decreases by

1 / -1 / 1- [2]

*Penalize missing + sign or incorrect notation
such as 2+ or II, once only.*

(ii) nitric acid / HNO_3 / NO_3^- / nitrate [1]

- (b) (i) 0.100×0.0285
 $2.85 \times 10^{-3} \text{ (mol)}$ [2]

Award [2] for correct final answer.

(ii) $2.85 \times 10^{-3} \text{ (mol)}$ [1]

(iii) $(63.55 \times 2.85 \times 10^{-3}) = 0.181 \text{ g}$ [1]

Allow 63.5.

(iv) $(0.181/0.456 \times 100 =) 39.7\%$ [1]

(v) $(44.2 - 39.7/44.2 \times 100 =) 10/10.2\%$ [1]

*Allow 11.3%, i.e. percentage obtained in (iv)
is used to divide instead of 44.2%.*

- 18 (a) Oxidized: $\text{S} -2 \rightarrow 0$
Reduced: $\text{O } 0 \rightarrow -2$ [4]

- (b) Reducing agent is H_2S
Reduces $\text{SO}_2(\text{g})$ to $\text{S}(\text{s})$ /is oxidized from
 $\text{H}_2\text{S}(\text{g})$ to $\text{S}(\text{s})$ [2]

- (c) pH increases
 SO_2 and H_2S are both acids that are used up
in the reaction. [2]

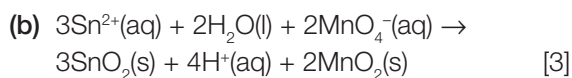
- (d) Release of $\text{SO}_2(\text{g})$ can lead to acid rain.
 $\text{SO}_2(\text{g})$ dissolves in water to form weakly acid
solutions. [2]

- 19 (a) $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$ [2]

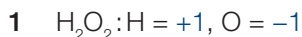
- (b) Oxidation of zinc occurs preferentially.
Protects the iron from oxidation. [2]

- (c) Iron rusts/corrodes/flakes off.
Colour changes, forming dark red/black
patches. [2]

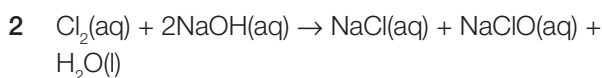
- 20 (a) The equation is balanced for atoms/
elements.
The equation is not balanced for charge. [2]



Challenge yourself



Oxygen is halfway between 0 (element) and -2 (usual oxidation state in compounds), so can be oxidized (to 0) or reduced (to -2). It will more easily be reduced from -1 to -2 as it is a very electronegative element, and so acts mainly as an oxidizing agent.



Cl changes from 0 to -1 (reduction)

Cl changes from 0 to +1 (oxidation)

Both changes occur simultaneously.

3 Iodine solution contains the triiodide ion, I_3^{-} , in which the central atom has five electron domains with two bonding and three non-bonding pairs in the equatorial plane. This gives a linear ion with a low charge density, which is able to slip into the coils of the hydrophobic interior of the amylose helix.

4 Solubility of gases decreases with increasing temperature as evaporation is higher. So the discharge of hot water will lower the dissolved O_2 content.

Answers

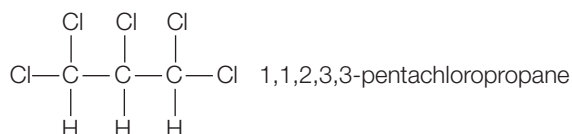
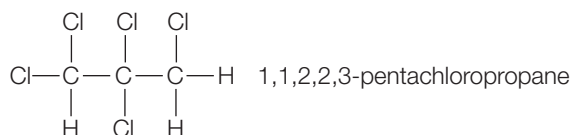
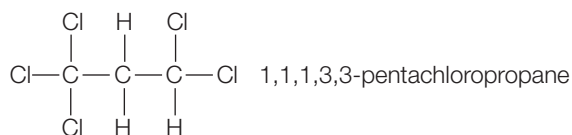
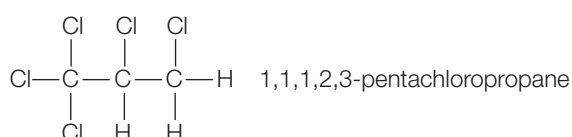
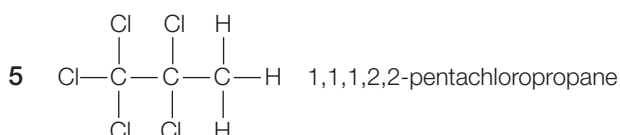
Chapter 10

Exercises

- 1 (a) carboxylic acid; butanoic acid
 (b) halogenoalkane; 1,1-dichloropropane
 (c) ketone; butanone
 (d) ester; methyl ethanoate
 (e) ether; methoxyethane
 (f) ester; ethyl pentanoate

- 2 (a) $\text{CH}_3(\text{CH}_2)_4\text{COOH}$
 (b) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$
 (c) $\text{CH}_2\text{CH}(\text{CH}_2)_2\text{CH}_3$
 (d) $\text{CH}_2\text{BrCH}(\text{CH}_3)\text{C}_2\text{H}_5$
 or $\text{CH}_2\text{BrCH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
 (e) $\text{HCOOCH}_2\text{CH}_3$
 (f) $\text{CH}_3\text{OCH}_2\text{CH}_2\text{CH}_3$
 (g) $\text{CH}_3\text{C}\equiv\text{CCH}_3$

- 3 A 4 D



- 6 B

- 7 Benzene is a cyclic molecule with a planar framework of single bonds between the six carbon atoms and six hydrogen atoms. The carbon atoms are also bonded to each other by a delocalized cloud of electrons which forms a symmetrical region of electron density above and below the plane of the ring. This is a very stable arrangement, so benzene has much lower energy than would be expected.

- 8 (a) Similar molar mass will mean molecules have approximately equal London (dispersion) forces and so differences in boiling point can be attributed to differences in dipole-dipole or hydrogen bonding.

- (b) Solubility in hexane will increase with increasing chain length as the non-polar part of the molecule makes a larger contribution to its structure.

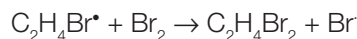
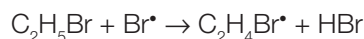
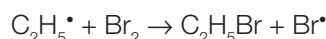
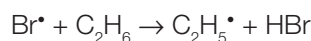
- 9 (a) $\text{C}_5\text{H}_{14}(\text{l}) + 6\text{O}_2(\text{g}) \rightarrow 5\text{CO}(\text{g}) + 7\text{H}_2\text{O}(\text{l})$
 (b) $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l})$
 (c) $\text{C}_3\text{H}_4(\text{g}) + \text{O}_2(\text{g}) \rightarrow 3\text{C}(\text{s}) + 2\text{H}_2\text{O}(\text{l})$

- 10 Bromine + ethane

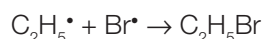
initiation



propagation



termination



Overall, these reactions show how a mixture of products is formed.

- 11 (a) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ butane
 (b) $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$ butan-2-ol
 (c) $\text{CH}_3\text{CH}_2\text{CHBrCH}_3$ 2-bromobutane
- 12 (a) No observable change.
 (b) Burns with very smoky flame.
 (c) The bromine water changes from brown to colourless.
- 13 (a) $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2 \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$
 $2\text{C}_3\text{H}_7\text{OH}(\text{l}) + 9\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 8\text{H}_2\text{O}(\text{l})$
 (b) $\text{C}_2\text{H}_5\text{COOH}(\text{aq}) + \text{C}_4\text{H}_9\text{OH}(\text{aq}) \rightarrow$
 $\text{C}_2\text{H}_5\text{COOC}_4\text{H}_9(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- 14 (a) butanone; orange \rightarrow green
 (b) methanal; orange \rightarrow green
 (c) no reaction; no colour change
- 15 Nucleophilic substitution involves an electron-rich species (e.g. OH^-) attacking an electron-deficient carbon atom (e.g. in chloroethane), leading to substitution of the halogen functional group by the nucleophile.
 $\text{C}_2\text{H}_5\text{Cl} + \text{OH}^- \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{Cl}^-$
- 16 Benzene has a very stable structure as a result of its symmetrical ring of delocalized electrons. Addition reactions would involve breaking this ring and therefore decreasing its stability. Substitution reactions in which one or more hydrogen atoms of the ring are replaced by other atoms or groups preserves the aromatic ring structure and therefore its stability.

Practice questions

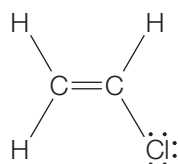
For advice on how to interpret the marking below please see Chapter 1.

- | | | | |
|-----|------|------|------|
| 1 C | 2 A | 3 A | 4 A |
| 5 B | 6 A | 7 A | 8 A |
| 9 C | 10 B | 11 C | 12 A |
- 13 B

- 14 A: 1-bromobutane
 B: 2-bromobutane
 C: 2-bromo-2-methylpropane
 D: 1-bromo-2-methylpropane [4]
Penalize incorrect punctuation, e.g. commas for hyphens, only once.
Accept 2-bromomethylpropane and 1-bromomethylpropane for C and D respectively.

- 15 (a) Colour change from yellow / orange / rust colour / red / brown to colourless [1]
No mark for change to clear, or for decolorized with no reference to original colour.

- (b) Chloroethene:



No mark if the lone pairs are missing on Cl.
Accept lines, dots or crosses for e^- pairs.

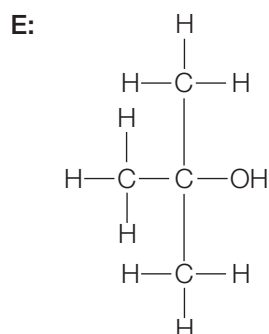
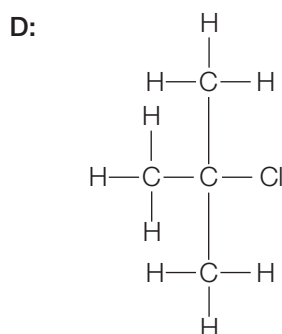
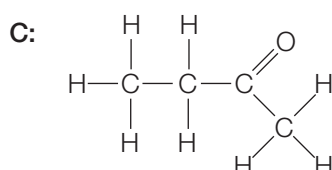
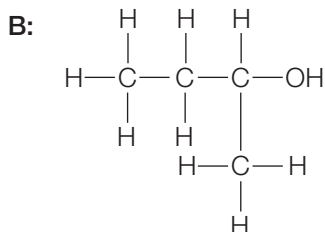
Poly(chloroethene):



n and square brackets are not required.
Continuation bonds must be shown.

- (c) (hydration of ethene for the manufacture of) ethanol / $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH}$; (synthesis of) CH_3COOH / ethanoic / acetic acid; (synthesis of) ethylene glycol / 1,2-ethanediol / ethane-1,2-diol; (synthesis of) drugs / pesticides; (hydrogenation of unsaturated oils in the manufacture of) margarine [2 max]
Accept other commercial applications.

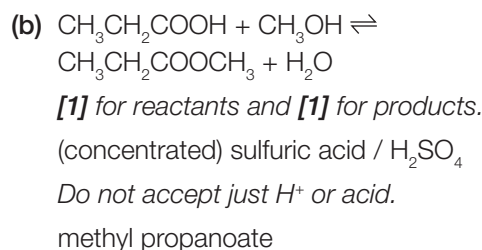
- 16 (a) A:
- $$\begin{array}{ccccc} & \text{H} & & \text{H} & & \text{H} \\ & | & & | & & | \\ \text{H} - & \text{C} & - & \text{C} & - & \text{C} & - & \text{Cl} \\ & | & & | & & | \\ & \text{H} & & \text{H} & & \text{H} - \text{C} - \text{H} \\ & & & & & | \\ & & & & & \text{H} \end{array}$$



Accept condensed formulas.

[5]

Award **[1 max]** if **A** and **D** are other way round (and nothing else correct). Award **[2 max]** if **A** and **D** are other way round but one substitution product **B** or **E** is correct based on initial choice of **A** and **D**. Award **[3 max]** if **A** and **D** are other way round but both substitution products **B** and **E** are correct based on initial choice of **A** and **D**. M2 (for **B**) and M5 (for **E**) may also be scored for substitution product if primary chloroalkane used. Penalize missing hydrogens once only.



- 17 (a) (the solution changes) from orange to green [1]
 (b) +6 [1]
 Do not accept 6, 6+ or the use of Roman numerals unless they have already been penalized in 2(a).
 (c) $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$ [1]
 (d) $\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} + 2\text{H}^+ + 2\text{e}^-$
 $\text{Cr}_2\text{O}_7^{2-} + 3\text{CH}_3\text{CH}_2\text{OH} + 8\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{CH}_3\text{CHO} + 7\text{H}_2\text{O}$ [3]
 For second equation award **[1]** for correct reactants and products and **[1]** for correct balancing.
 (e) H^+ is a reactant / OWTTE [1]
 (f) ethanoic acid / CH_3COOH / acid [1]
 Accept acetic acid.

Challenge yourself

- Complete combustion:
 $2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}$
 C: $-3 \rightarrow +4$
 Incomplete combustion:
 $2\text{C}_2\text{H}_6 + 5\text{O}_2 \rightarrow 4\text{CO} + 6\text{H}_2\text{O}$
 C: $-3 \rightarrow +2$
- Heterolytic describes breaking of the bond, producing two *different* products. The products are ions, and the reaction mechanism involves attraction of the electron density of the $\text{C}=\text{C}$ double bond to the positive ion.
- The repeating unit in polystyrene is $-\text{CH}(\text{C}_6\text{H}_5)-\text{CH}_2-$

Answers

Chapter 11

Exercises

- 1 The smallest division is 1 so the uncertainty is ± 0.5 .
- 2 The missing diamond has a mass of between 9.87 and 9.97 g.
The found diamond has a mass between 9.9 and 10.3 g.
As the ranges overlap, it **could** be the missing diamond.
- 3 (a) 4×10^{-2} g (b) 2.22×10^2 cm³
(c) 3.0×10^{-2} g
(d) 3×10 or 3.0×10 °C (unspecified)
- 4 (a) 4 (b) unspecified
(c) 3 (d) 4
- 5 A 6 A 7 B 8 A
9 B 10 D 11 C
- 12 The average value = 49.0 s
The uncertainty in the measurements is given as ± 0.1 s but the results show that there is additional uncertainty, suggesting that the value could be anywhere between 48.8 and 49.2 s. So the value could be quoted as $49.0 \text{ s} \pm 0.2 \text{ s}$.
- 13 Note that the correct solution to this question is not one of the possible answers listed.
The temperature change expressed to the appropriate precision is 2.05 ± 0.05 K.
- 14 D 15 B 16 B 17 C
18 A 19 C
- 20 Number of moles = concentration \times volume/1000
 $= 1.00 \times 10.0/1000 = 0.0100$ mol
% uncertainty in concentration = $(0.05/1.00) \times 100 = 5\%$
% uncertainty in volume = $(0.1/10.0) \times 100 = 1\%$
% uncertainty in number of moles = $5\% + 1\% = 6\%$
Absolute uncertainty in number of moles = $(6/100) \times 0.0100 = 0.0006$
Number of moles = 0.0100 ± 0.0006 mol
- 21 (a) $\Delta T = 43.2 - 21.2^\circ\text{C} = 22.0^\circ\text{C}$
absolute uncertainty = $(\pm)0.2^\circ\text{C}$
(b) % uncertainty = $0.2/22.0 \times 100\% \approx 1\%$
(c) $\Delta H = -4.18 \times 22.0/0.500 = -184 \text{ kJ mol}^{-1}$
(d) 1%
(e) Absolute uncertainty = $1/100 \times 184 = (\pm) 2 \text{ kJ mol}^{-1}$
(f) Experimental value for $\Delta H = -184 (\pm) 2 \text{ kJ mol}^{-1}$
The literature value is outside this range.
The random errors involved in reading the thermometer do not account for this difference.
There are systematic errors. The assumptions on which the calculation is based are not strictly valid. Some of the heat of reaction passes into the surroundings and the other uncertainties in the measurements cannot be ignored. It should also be noted that the standard value for ΔH refers to standard conditions of 298 K and 100 kPa.
- 22 B
- 23 The scale of the graph does not allow us to distinguish whether A or B is the best answer and both are acceptable.
- 24 B
- 25 Concentration of chromium (from graph for absorbance of 0.215) = $3.34 \mu\text{g dm}^{-3}$
- 26 C 27 C
- 28 A (the spectrum on the left) corresponds to $\text{CH}_3\text{CH}_2\text{CHO}$
B (the spectrum on the right) corresponds to CH_3COCH_3

Similarities

Both have a molecular ion corresponding to 58.

Differences

A has peaks corresponding to 29 (CH_3CH_2^+) and 28 (loss of CH_3CH_2).

B has a peak corresponding to 43 (loss of CH_3).

29 (a)	Mass / charge	Fragment
	15	CH_3^+
	29	C_2H_5^+
	43	C_3H_7^+ (loss of CH_3)
	58	$\text{C}_4\text{H}_{10}^+$

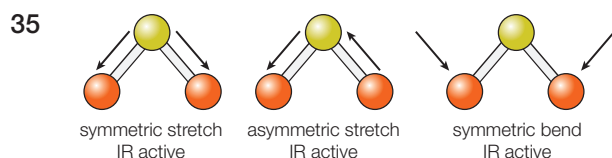
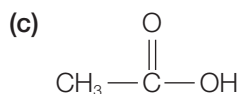
(b) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$

30	Molecule	Corresponding saturated non-cyclic molecule	IHD
	C_6H_6	C_6H_{14}	4
	CH_3COCH_3	$\text{C}_3\text{H}_8\text{O}$	1
	$\text{C}_7\text{H}_6\text{O}_2$	$\text{C}_7\text{H}_{16}\text{O}$	5
	$\text{C}_2\text{H}_3\text{Cl}$	$\text{C}_2\text{H}_5\text{Cl}$	1
	$\text{C}_4\text{H}_9\text{N}$	$\text{C}_4\text{H}_{11}\text{N}$	1
	$\text{C}_6\text{H}_{12}\text{O}_6$	$\text{C}_6\text{H}_{14}\text{O}_6$	1

31 B 32 D 33 B

34 (a) Empirical formula CH_2O . Molecular formula $\text{C}_2\text{H}_4\text{O}_2$.

(b) IHD = 1



36 B

37 The polarity (of bond or molecule) changes as the bonds are bent or stretched.

38 Hex-1-ene shows an absorption in the range $1610\text{--}1680\text{ cm}^{-1}$ due to the presence of the $\text{C}=\text{C}$ bond.

39 C—H bond

40 CH_3OCH_3

2

41 C 42 A

43 (a) 2 (b) 1
(c) 1 (d) 2

44 The H atoms are in three different environments so there will be three peaks in the ^1H NMR spectrum with integrated areas in the ratio 3:2:1.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 B 2 C 3 C 4 A

5 (a) Compound:



Explanation: [1 max]

only this compound would give 3 peaks / OWTTE

only this compound has H atoms in 3 different chemical environments / OWTTE

only this compound has protons in ratio 3:2:1 in each environment / OWTTE

only this compound would give a peak in the 9.4–10 ppm region / OWTTE [2 max]

(b) 2.5 ppm peak

$\text{CH}_3 - \text{CO} - \text{CH}_3$ also has hydrogen atoms on a carbon next to the $>\text{C}=\text{O}$ group [2]

(c) (i) $1700\text{--}1750\text{ cm}^{-1}$ ($>\text{C}=\text{O}$) [1]

(ii) $1610\text{--}1680\text{ cm}^{-1}$ ($>\text{C}=\text{C}<$) / $3200\text{--}3600\text{ cm}^{-1}$ ($-\text{O}-\text{H}$) [1]

(d) $\text{C}_3\text{H}_6\text{O}^+$ and $m/z = 58$

C_2H_5^+ and $m/z = 29$

CHO^+ and $m/z = 29$

CH_3^+ and $m/z = 15$ [2 max]

Penalize missing + sign once only.

6 (a) (stretches/vibrations in) HBr involve change in bond dipole / (stretches/vibrations in) Br_2 do not involve change in bond dipole [1]

- (b) (i) I: O—H
 II: C—H
 III: C=O [3]
 Award [2] for C—H for I and O—H for II.

- (ii) m/z 102: molecular ion peak /
 $(\text{CH}_3)_3\text{CCOOH}^+ / \text{C}_5\text{H}_{10}\text{O}^+ / \text{M}^+$
 m/z 57: $(\text{CH}_3)_3\text{C}^+ / (\text{M}-\text{COOH})^+ / \text{C}_4\text{H}_9^+$
 m/z 45: COOH^+ [3]

Penalize missing + once only.

- (iii) (H of) COOH group [1]

- (iv) nine hydrogens in the same environment / $(\text{CH}_3)_3\text{C}-$ (group) [1]

- (v) $(\text{CH}_3)_3\text{CCOOH} / (\text{CH}_3)_3\text{CCO}_2\text{H} / \text{H}_3\text{C}-\text{C}(\text{CH}_3)(\text{O})=\text{C}-\text{OH}$ [1]

- (vi) no peak at 11.5 ppm in spectrum of isomer / different chemical shift values
 four peaks (instead of two) / different number of peaks;
Three of these peaks can be split in actual spectrum, so allow for this in answers if exactly four peaks is not stated.
 different integration trace / different areas under the peaks / integration trace would have a 3:2:2:3 peak area ratio [2 max]
Do not award mark if incorrect peak area ratios are given for the structure drawn in (v).

- 7 change in bond length / bond stretching / asymmetric stretch
 change in bond angle / bending (of molecule)
 Allow [1 max] for only stating vibrations.
 induces molecular polarity / dipole moment / OWTTE [3]

- 8 (a) $\text{C}_3\text{H}_8\text{O}^+$ [1]

Accept more detailed formula such as $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}^+$.

- (b) $\text{CH}_3\text{O}^+ / \text{CH}_2\text{OH}^+$ [1]

For (a) and (b), if charge is missing penalize once only.

- (c) (A) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
 Accept more detailed formula.

- (B) $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ [2]

Accept more detailed formula.

Hydrogen(s) missing, penalize once only.

Award [1] if both structures correct but the wrong way round.

- 9 (a) A: O—H

B: C=O

C: C—O

Award [2] for three correct, [1] for two correct. [2]

- (b) $m/z = 74: \text{C}_2\text{H}_5\text{COOH}^+ / \text{C}_3\text{H}_6\text{O}_2^+$

$m/z = 45: \text{COOH}^+$

$m/z = 29: \text{C}_2\text{H}_5^+$

Penalize missing + charge once only.

Do not award mark for $m/z = 29: \text{CHO}^+$. [3]

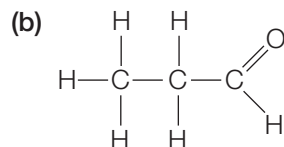
- (c) $-\text{COOH}$ [1]

- (d) $\text{CH}_3\text{CH}_2\text{COOH} / \text{CH}_3\text{CH}_2\text{CO}_2\text{H}$

More detailed structural formula may be given. [1]

- 10 (a) absence of peak between 3200 and 3600 cm^{-1} / above 3000 cm^{-1} / peak for OH
 presence of peak between 1700 and 1750 cm^{-1} / peak for C=O

absence of peak between 1610 and 1680 cm^{-1} / peak for C=C [2 max]



Accept $\text{CH}_3\text{CH}_2\text{CHO}$.

3:2:1

Ignore order.

ECF if structure is incorrect only if its NMR spectrum contains three peaks. [2]

- 11 (a) (i) (2-)methylpropan-2-ol

the (H atoms in the three) $-\text{CH}_3$ groups are responsible for the peak at 1.3 ppm

the $-\text{OH}$ hydrogen atom is responsible for the peak at 2.0 ppm

Accept explanations with suitable diagram.

[3]

(ii) (2-)methylpropan-1-ol

the first peak (at 0.9 ppm) is due to the (H atoms in the) two $-\text{CH}_3$ groups (bonded to the second carbon atom) / $(\text{CH}_3)_2\text{CHCH}_2\text{OH}$

the peak at 3.4 ppm is due to the (H atoms in the) $-\text{CH}_2-$ group / $(\text{CH}_3)_2\text{CHCH}_2\text{OH}$

Accept explanations with suitable diagram.

[3]

(b) (i) butan-1-ol and butan-2-ol

74: $\text{M}^+ / \text{C}_4\text{H}_{10}\text{O}^+ / \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}^+$
and $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3^+$

59: $\text{C}_3\text{H}_7\text{O}^+ / (\text{M} - \text{CH}_3)^+ /$
 $\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}^+$ and $\text{CH}_2\text{CH}(\text{OH})\text{CH}_3^+ /$
 $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})^+$

45: $\text{C}_2\text{H}_5\text{O}^+ / (\text{M} - \text{C}_2\text{H}_5)^+ / \text{CH}_2\text{CH}_2\text{OH}^+$
and $\text{CH}(\text{OH})\text{CH}_3^+$

Accept explained answers instead of formulas.

[4]

(ii) butan-1-ol

$\text{CH}_2\text{OH}^+ / (\text{M} - \text{C}_3\text{H}_7)^+$

Penalize missing + signs once only in parts (b)(i) and (ii).

[2]

(c) they all contain O—H

they all contain C—H

they all contain C—O

Award [1 max] for same functional groups/bonds.

[2 max]

$$3 \quad Y_1^{\text{ave}} = Y_2^{\text{ave}} = 3$$

$$R = \frac{(-2 \times (-2)) + (-1 \times 2) + 0 + (1 \times 1) + (2 \times (-1))}{2^2 + 1^2 + 0^2 + 1^2 + 2^2} = \frac{4 - 2 + 1 - 2}{10} = 0.10$$

4 Saturated hydrocarbons have the general formula $\text{C}_n\text{H}_{2n+2}$

For C_nH_p :

H atoms needed = $2n + 2 - p$

H_2 molecules needed = IHD = $\frac{1}{2}(2n + 2 - p)$

For $\text{C}_n\text{H}_p\text{O}_q$:

Oxygen forms two covalent bonds. Comparing ethane, C_2H_6 : C—H, to ethanol, $\text{C}_2\text{H}_5\text{OH}$: C—O—H, we see that the presence of O has no impact on the IHD:

$$\text{IHD} = \frac{1}{2}(2n + 2 - p)$$

For $\text{C}_n\text{H}_p\text{O}_q\text{N}_r$:

Nitrogen forms three covalent bonds. Comparing C—H to C—N—H, we see that the presence of one N increases the IHD by 1:

$$\text{IHD} = \frac{1}{2}(2n + 2 - p + r)$$

For $\text{C}_n\text{H}_p\text{O}_q\text{N}_r\text{X}_s$:

A halogen, X, forms one bond, like hydrogen, so can be treated in the same way:

$$\text{IHD} = \frac{1}{2}(2n + 2 - p + r - s)$$

5 $E = h\nu$

$$E = 6.63 \times 10^{-34} \text{ J s} \times 3.0 \times 10^{14} \text{ s}^{-1} = 2.0 \times 10^{-19} \text{ J}$$

$$\begin{aligned} \text{The energy of one mole of photons} &= 6.02 \times 10^{23} \text{ mol}^{-1} \times 2.0 \times 10^{-19} \text{ J} \\ &= 120 \text{ kJ mol}^{-1} \end{aligned}$$

$$6 \quad 1/\lambda = 2100 \text{ cm}^{-1} = 210000 \text{ m}^{-1}$$

$$\lambda = 1/210000 \text{ m} = 4.76 \times 10^{-6} \text{ m}$$

$$\nu = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{4.762 \times 10^{-6} \text{ m}} = 6.30 \times 10^{13} \text{ s}^{-1}$$

Challenge yourself

$$1 \quad Y_1^{\text{ave}} = Y_2^{\text{ave}} = 3$$

$$R = \frac{(-2 \times (-2)) + (-1 \times (-1)) + 0 + (1 \times 1) + (2 \times 2)}{(-2)^2 + (-1)^2 + 0^2 + 1^2 + 2^2} = 1$$

$$2 \quad Y_1^{\text{ave}} = Y_2^{\text{ave}} = 3$$

$$R = \frac{(-2 \times 2) + (-1 \times 1) + 0 + (1 \times (-1)) + (2 \times (-2))}{(-2)^2 + (-1)^2 + 0^2 + 1^2 + 2^2} = -1$$

Answers

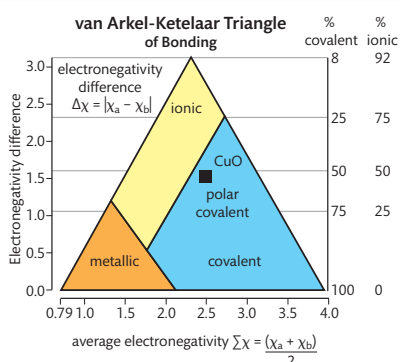
Chapter 12

Exercises

1 A

Substance	χ_{average}	$\Delta\chi$	% ionic character	Bonding
Cl_2O	3.3	0.2	6	(Polar) covalent
PbCl_2	2.5	1.4	44	Polar covalent
Al_2O_3	2.5	1.8	56	Ionic
HBr	2.6	0.8	25	Polar covalent
NaBr	1.95	2.1	66	Ionic

The % ionic character is taken from the bonding triangle (Figure 12.1).

Substance	χ_{average}	$\Delta\chi$	% ionic character	Bonding
CuO	2.65	1.5	47	 <p>The diagram is a triangle with vertices at (0.79, 0.0), (4.0, 0.0), and (2.5, 3.0). The left side is labeled 'ionic', the bottom-left is 'metallic', and the bottom-right is 'covalent'. A point for CuO is marked at approximately (2.65, 1.5), which corresponds to 47% ionic character. The x-axis is 'average electronegativity $\bar{\chi} = (\chi_a + \chi_b)/2$' and the y-axis is 'electronegativity difference $\Delta\chi = \chi_a - \chi_b$'.</p>

- 4 Metal atoms can slide across each other with the metallic bonding not breaking as the delocalized electrons can move to accommodate the changes in the lattice.

The ionic and covalent bonds are directional and more rigid in ceramics. They resist changes in the atomic arrangement but will break if the applied forces are too strong.

- 5 Concrete can contain iron or carbon fibres. If these are connected into a network within the concrete the material will conduct electricity along the network.

6 (a) Bauxite

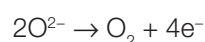
(b) Aluminium is more reactive than carbon.

(c) Aluminium ions are attracted towards the negative electrode where they are reduced to aluminium atoms: $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$

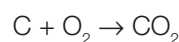
(d) Aluminium is more reactive than hydrogen. Hydrogen gas would be produced as the hydrogen from the water is reduced in preference to the aluminium.

(e) Aluminium oxide is only 56% ionic based on electronegativity values. The ions are not completely free in the molten compound.

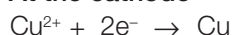
(f) Oxygen is produced at the anode from the oxide ions:



The oxygen reacts with the carbon to produce carbon dioxide:



7 At the cathode



1 mol 2 mol 1 mol

$$n(\text{Cu})/n(\text{e}^-) = 1/2$$

$$n(\text{Cu}) = (1/2)n(\text{e}^-)$$

$$0.100 \text{ F} = 0.100 \text{ mol of e}^-$$

$$n(\text{Cu}) = 0.050 \text{ mol}$$

$$m(\text{Cu}) = 0.050 \text{ mol} \times 63.55 \text{ g mol}^{-1} \\ = 3.2 \text{ g}$$

At the anode



2 mol 1 mol 2 mol

$$n(\text{Cl}_2)/n(\text{e}^-) = 1/2$$

$$n(\text{Cl}_2) = (1/2)n(\text{e}^-)$$

$$0.100 \text{ F} = 0.100 \text{ mol of e}^-$$

$$n(\text{Cl}_2) = 0.050 \text{ mol}$$

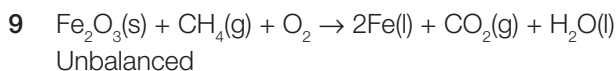
$$V(\text{Cl}_2) = 0.050 \text{ mol} \times 22.4 \text{ dm}^3 \text{ mol}^{-1} \\ = 1.1 \text{ dm}^3$$

8 $n(\text{e}^-) = 0.0965 \text{ A} \times 1000 \text{ s} / 96\,500 \text{ C mol}^{-1} =$
 $96.5 / 96\,500 = 0.00100 \text{ mol}$

$$n(\text{Ti}) = 0.011975 / 47.9 = 0.000250 \text{ mol}$$

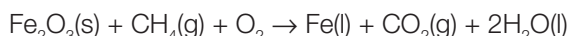
$$n(\text{e}^-)/n(\text{Ti}) = 4$$

Ti is in the +4 state. Formula: TiCl_4



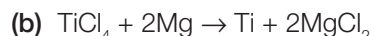
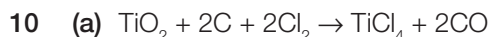
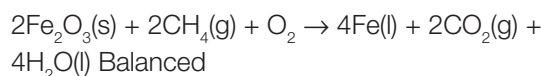
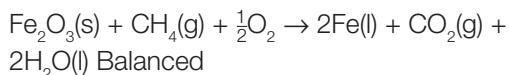
Balance the elements only present in a combined state first.

Balance the C and H:



Unbalanced

Balance the Fe and O:



11 The alloy is stronger than the pure metal.

Adding atoms of different size disrupts the regular metal lattice so that it is difficult for one layer to slide over another. Alloying can make the metal harder, stronger and more resistant to corrosion.

12 All of the electron spins are paired in diamagnetic elements.

Atoms are paramagnetic if they have unpaired electrons. So, to determine whether the elements are paramagnetic or diamagnetic, we need to consider the electron configuration for each element.

Element	Electron config.	No. of unpaired electrons	Magnetic behaviour
Na	$[\text{Ne}]3\text{s}^1$	1	para
Mg	$[\text{Ne}]3\text{s}^2$	0	dia
Al	$[\text{Ne}]3\text{s}^23\text{p}^1$	1	para
Si	$[\text{Ne}]3\text{s}^23\text{p}^2$	2	para
P	$[\text{Ne}]3\text{s}^23\text{p}^3$	3	para
S	$[\text{Ne}]3\text{s}^23\text{p}^4$	2	para
Cl	$[\text{Ne}]3\text{s}^23\text{p}^5$	1	para
Ar	$[\text{Ne}]3\text{s}^23\text{p}^6$	0	dia

Phosphorus has the most unpaired electrons and so is the most paramagnetic.

13

Atom	K	Sc	V	Mn	Ga	As
Electron configuration	$[\text{Ar}]4\text{s}^1$	$[\text{Ar}]3\text{d}^14\text{s}^2$	$[\text{Ar}]3\text{d}^34\text{s}^2$	$[\text{Ar}]3\text{d}^54\text{s}^2$	$[\text{Ar}]3\text{d}^{10}4\text{s}^24\text{p}^1$	$[\text{Ar}]3\text{d}^{10}4\text{s}^24\text{p}^3$
No. of unpaired electrons	1	1	3	5	1	3

$$\text{K} \approx \text{Sc} \approx \text{Ga} < \text{V} \approx \text{As} < \text{Mn}$$

- 14 (a) Positive argon ions and (free) electrons.
 (b) Argon, as it is present in the plasma.
 (c) ICP-MS
 (d) ICP-AES, ICP-MS is less effective with non-metals as they have higher ionization energies and so form positive ions less readily.
- 15 (a) Different calibrations are produced for each electron transition so three transitions are analysed.
 (b) It produced 3.00×10^7 counts in one minute = $0.0500 \times 10^7 \text{ c s}^{-1} = 5.00 \times 10^5 \text{ c s}^{-1} = 500 \text{ kc s}^{-1}$
 From the graph and line II, [Hg] is between 1.9 and $2.0 \mu\text{g dm}^{-3}$
 (c) 798 kc s^{-1}
 (d) Series I, as it has the steepest gradient; small differences in concentration can be detected with large differences in count rate.
- 16 0.37% by mass
- 17 Transition metals are effective heterogeneous catalysts as they form weak bonds to small reactant molecules which allow them to come together with the correct orientation.
 The ability of transition metals to show variable oxidation states allows them to be particularly effective homogeneous catalysts.
- 18 (a) Lower temperatures needed so reduced energy costs.
 Catalysts act selectively, increasing the yield of the desired product. They are not used up and so can be reused over long periods of time.
 (b) Sulfur impurities block the active sites of the catalyst; the impurities are adsorbed on the catalyst surface more strongly than reactant molecules.
- 19 (a) An activated complex is an unstable combination of reactant molecules that can go on to form products or fall apart to form reactants. A reaction intermediate is a species that is produced and consumed during a reaction but does not occur in the overall equation.

An activated complex corresponds to a maximum in the energy and a reaction intermediate corresponds to a local minimum in energy. Reaction intermediates can in theory be isolated.

- (b) Heterogeneous catalysts are in a different phase from the reactants; they can be easily removed by filtration.
 (c) They have a large surface area per unit mass for reactants to be adsorbed and their surface structure can be modified to improve effectiveness.
 (d) Toxicity of the nanoparticles is dependent on their size, so need to regulate for type of material and size of particles.

20 (a)

	Liquid	Liquid crystal
Molecular arrangement	disordered	disordered
Molecular orientation	disordered	ordered

- (b) The phase transitions of thermotropic liquid crystals depend on temperature.
 The phase transitions of lyotropic liquid crystals depend on both temperature and concentration.
 (c) The molecules/ions group together to form a spherical arrangement; the hydrophilic heads are exposed to water, shielding the non-polar tails.

21 Thermotropic liquid crystal materials are pure substances that show liquid crystal behaviour over a temperature range between the solid and liquid states. Example: biphenyl nitriles.

Lyotropic liquid crystals are solutions that show the liquid crystal state at certain concentrations. Examples: soap and water, Kevlar® in solution.

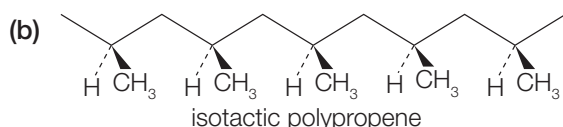
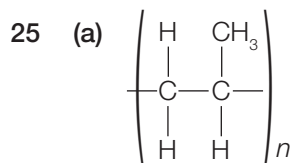
- 22 (a) Low reactivity of C—H and C—C bonds due to high bond energy and low polarity.
 (b) Increases polarity. Molecule can change orientation when an electric field is applied.

23 (a) $\text{C}_{24}\text{H}_{23}\text{N}$

- (b) The addition of a benzene ring makes the molecule more rigid and rod-shaped.

24 A

There are strong C—C covalent bonds within the chains and relatively strong intermolecular forces between the large polymer chains.



- (c) Isotactic polypropene has a regular structure with the methyl groups pointing in the same direction and so is crystalline and tough.

(d) $M_r = (3 \times 12.01) + (6 \times 1.01) = 42.09$

$n = 2.1 \times 10^6 / 42.09 = 50\,000$

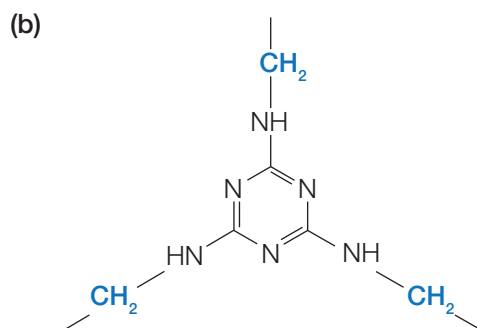
- (e) The chains in a polymer are not all the same length.

- 26 (a) The pure form, which has strong dipole–dipole interactions between the chains, is hard and brittle. The addition of plasticizers allows the chains to slip across each other and makes the plastic more flexible.

- (b) The non-expanded form of polystyrene is a colourless, transparent, brittle plastic. The expanded form is opaque with a lower density. It is a better insulator and shock absorber.

The expanded form is produced by heating polystyrene beads with a volatile hydrocarbon such as pentane. The pentane evaporates and causes bubbles to form in the plastic.

- 27 (a) Relative molar mass of reactant =
 $(6 \times 12.01) + (24 \times 1.01) + (12 \times 14.01) + (6 \times 16.00) = 360.42$
 Relative molar mass of desired product =
 $(3 \times 12.01) + (6 \times 1.01) + (6 \times 14.01) = 126.15$
 Atom economy = $\frac{126.15}{360.42} \times 100\% = 35.0\%$



- (c) There are relatively weak intermolecular forces between the chains in polyethene. These forces are broken when the solid melts but are reformed when the liquid is cooled. The crosslinks between the chains in the thermosetting resin are made from strong covalent bonds. When heated to high temperature the resin does not melt but burns.
- (d) There is extensive cross-linking in thermosetting plastics which means they cannot be reshaped and do not melt when heated.

Elastomers have very limited cross-links which knot some chains together and prevent molecules slipping across each other without restricting the freedom of the molecules to coil and uncoil.

- 28 (a) Polystyrene can act as a good shock absorber. Its low density will reduce transport costs and make it easier to handle.
- (b) A volatile hydrocarbon is added during the polymerization process. The volatile hydrocarbon turns into a gas, forming bubbles that force the surrounding polymer to expand and take the shape of the mould.

- 29 (a) No. of diameters = $10 \times 10^{-6} \text{ m} / 1 \times 10^{-9} \text{ m} = 10^{-5} / 10^{-9} = 10^4 = 10\,000$
- (b) Strong covalent C—C bonds must be broken.
- (c) Range of tube lengths with different structures lead to a less regular structure in the solid, which reduces strength. As properties are sensitive to tube length, it is difficult to produce tubes with required properties.
- (d) Large surface area for reactants to be adsorbed; the shape and size of the tubes

make them shape-selective catalysts, only reactants of the appropriate geometry are able to interact effectively with the active sites.

- (e) Quantum effects predominate and the electrons behave like waves; the length of the tube affects the behaviour of electrons; the tubes are conductors or semiconductors depending on the length.

- 30 (a) The size of the nanoparticles is similar to the wavelength of harmful UV radiation. UV is scattered and not absorbed.

- (b) Toxicity of the nanoparticles is dependent on their size, so need to regulate for type of material and size of particles.

- 31 (a) Approx. 25 atoms high

Each C atom has a diameter of $2 \times 75 \times 10^{-12}$ m and each O atom has a diameter of $2 \times 64 \times 10^{-12}$ m

Approximate length = $25 \times 2 \times 70 \times 10^{-12}$ m
= 3.5×10^{-9} m

- (b) Scanning tunnelling microscope (STM) or atomic force microscope (AFM).

- 32 (a) Plastics are easily moulded; they are non-biodegradable; they have low density.

(b)	Method	Advantages	Disadvantages
	landfill	simple method to deal with large volumes	plastics are not biodegradable; limited sites
	incineration	reduces volume; plastics are concentrated energy source	CO ₂ is a greenhouse gas; CO is poisonous; HCl produced from combustion of PVC causes acid rain
	recycling	conserves natural resources	plastics need to be sorted

- (c) Bacteria do not have the enzymes needed to break the C—C bonds present.

- (d) Natural polymers (e.g. starch, cellulose or protein) can be added. Bacteria can break

down the natural polymers and so the bag is broken down into smaller pieces.

33

Method	Advantages	Disadvantages
landfill	efficient method to deal with large volumes	not popular with locals; needs to be maintained and monitored after use
incineration	reduces volume; energy source	can cause pollutants such as greenhouse gases and dioxins

- 34 *Advantages:* saves natural resources; saves energy; reduces pollution

Disadvantages: materials need to be sorted

- 35 (a) 1–5

- (b) 1–4

- 36 Both molecules have C—H bonds so they have strong absorptions between 2850 and 3090 cm⁻¹.

The monomer has a C=C bond not found in the polymer so it will have a weak absorption at 1620–1680 cm⁻¹.

Practice questions

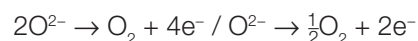
For advice on how to interpret the marking below please see Chapter 1.

- 1 (a) (i) melting point of the cryolite solution is much lower than the melting point of alumina / Al₂O₃ / it lowers the melting point of the mixture / cell operates at lower temperature [1]

Allow lowers melting point or lowers melting point of aluminium oxide.

Do not allow lowers melting point of aluminium.

- (ii) Positive electrode:



Negative electrode:



[2]

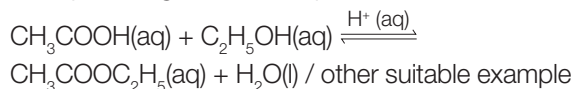
Award **[1]** for correct equations but wrong electrodes.

Allow e instead of e⁻.

- (b) use of fossil fuels (to provide energy)
oxidation of the (graphite) positive electrode / anode [2]
- 2 (a) Al is more reactive than Fe / Al is higher than Fe in the reactivity series / it is harder to reduce aluminium ores compared to iron ores / Fe³⁺ is a better oxidizing agent than Al³⁺ / OWTTE [2]
- (b) (i) $\text{Fe}_3\text{O}_4 + 4\text{CO} \rightarrow 3\text{Fe} + 4\text{CO}_2$ [1]
(ii) $\text{Fe}_3\text{O}_4 + 4\text{H}_2 \rightarrow 3\text{Fe} + 4\text{H}_2\text{O}$ [1]
- 3 (a) **homogeneous** mixture of metals / a metal and non-metal [1]
- (b) alloying element(s) disrupts regular / repeating (metal) lattice
difficult for one layer to slide over another / atoms smaller than the metal cations can fit into the (holes of) metal lattice disrupting bonding
can make metal harder / stronger / more corrosion resistant / brittle [2 max]

- 4 *Mode of action of homogeneous catalysis:*
catalyst reacts in one step (of the mechanism) and is regenerated at a later step / ability to form a range of oxidation states (for transition metals) / reaction steps with catalyst have lower activation energies than for reaction without catalyst / OWTTE

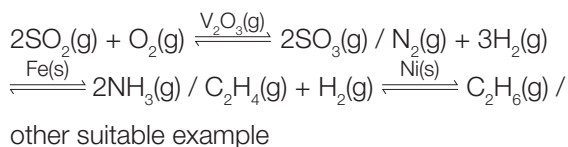
Example using chemical equation:



Mode of action of heterogeneous catalysis:

catalyst provides the reactive surface / presence of active sites / adsorb reactant molecule(s) (on surface)

Example using chemical equation:



Reversible sign not required for mark.

Catalyst and states must be specified to score mark. [4]

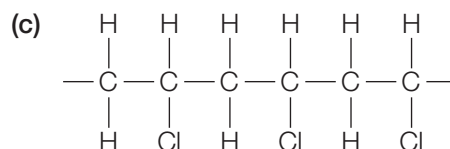
- 5 (a) biphenyl nitriles / cyanobiphenyls [1]
- (b) nitrile groups make molecule polar
intermolecular forces are strong enough to align in a common direction
biphenyl groups make molecules more rigid / rod-shaped
(long) alkane chain ensures that molecules cannot pack together closely (to maintain liquid-crystal state) [4]

- 6 (a) C–Cl bond / molecule is polar
stronger intermolecular / van der Waals / London / dispersion forces / dipole–dipole attraction [2]

- (b) addition of **plasticizers**

Allow misspelling within reason.

gets between polymer chains / keeps chains further apart **and** reduces attraction (between the chains) [2]



Accept any structure with all the Cl atoms shown on the same side.

Continuation bonds at end of structure not needed.

Hydrogen atoms must be included. [1]

- 7 makes the polymer low density / good thermal insulator / expanded / softer / better shock absorber

packaging/insulation

*Award **[1 max]** if thermal insulation given for both answers.* [2]

- 8 (a) 1 nm to 100 nm [1]
- (b) physical techniques move atoms to a specific position
chemical techniques involve chemical reactions to position atoms (in molecules)

Accept suitable examples for chemical techniques.

[2]

- (c) reference to effect on human health (e.g. unknown, immune system may not cope, unsatisfactory toxicity regulations)
reference to effect on employment (e.g. increased/decreased job opportunities, adverse effect on traditional industries)
reference to effect on quality of life (e.g. medical advances, faster computers, improved performance of electronic equipment)
reference to public opinion (e.g. need to improve information, encourage discussion, seek approval)
reference to nanotechnology being developed in wealthier nations hence increasing the divide between different nations [2 max]

9 Advantage:

reduce volume / stable odour-free residue / source of energy

Disadvantage:

expensive to build and operate / can form dioxins/toxic gases / requires energy / adds to greenhouse effect [2]

10 (a) Landfill:

can be used to deal with large volumes/ amounts / filled ground can be re-used / low cost

Do not accept 'no air pollution'.

Incineration:

reduces volume / requires minimal space / source of energy

Do not accept 'no land pollution'

Apply list principle, i.e. award [0] when one correct and one incorrect advantage given. [2]

- (b) limited supply of oxygen (prevents the bacteria from acting)

Do not accept air. [1]

11 (a) Positive electrode:

graphite / carbon

Negative electrode:

graphite / carbon (on a steel liner) [2]

- (b) much less energy required to recycle than to produce Al from ore / OWTTE
less production of CO₂/greenhouse gases (graphite used in the electrolysis is converted into CO₂) / the more that is recycled the less there will be in landfill sites / OWTTE [2]

- 12 (a) walls have rolled/single sheets of graphite / carbons bonded in hexagons
ends have half a buckyball (fullerene) / carbons in pentagons (and hexagons) [2]

- (b) covalent bonds are very strong [1]

- (c) (i) large surface area

Do not accept 'reactive surface'.

high selectivity related to dimensions of tube [2]

- (ii) unknown health effects

Accept potentially harmful as easily ingested/inhaled.

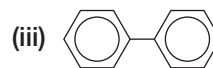
Accept difficulty of preparing nanotubes in required amounts. [1]

13 (a) (i) CN

makes molecule polar, ensures common orientation which can be changed by electric field

- (ii) C₅H₁₁

prevents close packing of molecules



molecules rigid and rod-shaped

Accept chemical stability for second or third mark not both. [3]

- (b) liquid crystal between two glass plates which have scratches at 90° to each other
molecules form a twisted arrangement between plates due to intermolecular bonds

when polarizers are aligned with scratches, light will pass through film and pixel will appear bright

applied voltage aligns polar molecules **and**
pixel appears dark [4]

- 14** (rod-shaped) molecules aligned in the same direction
increasing temperature causes arrangement to lose its directional order / molecules to become more randomly arranged until normal liquid state occurs [3]

- 15** HDPE:
no / very few branches
chains pack closer together
stronger intermolecular forces
Allow converse argument, e.g. LDPE has more branches, so its chains are further apart and the intermolecular forces are weaker. [4]

- 16** (a) addition of plasticizers
more flexible / flexibility [2]
(b) *polymer disadvantages*
difficult to dispose of polymer properly
fills up landfill sites
litter
lack of biodegradability
use of natural resources
Award [1] each for any two.
PVC disadvantages
burning produces toxic gases / HCl [3 max]

- 17** (a)
$$\begin{array}{c} \text{CH}_3 \quad \text{H} \\ \diagdown \quad \diagup \\ \text{C} = \text{C} \\ \diagup \quad \diagdown \\ \text{H} \quad \text{H} \end{array} \quad / \quad \text{CH}_3 - \text{CH} = \text{CH}_2$$
 [1]

- (b) melting point
Do not accept boiling point.
softness / hardness / flexibility / strength / rigidity / density [2]
(c) atactic
methyl groups arranged randomly / OWTTE [2]

Challenge yourself

- 1** (a) The molecule is rigid and rod-shaped.
(b) Thermotropic.
- 2** (a) The observer can see nothing. The whole area would appear dark as the polarizer and analyser are crossed.
(b) The whole area would appear light as the liquid crystal rotates the plane of polarization, so light is now transmitted by the analyser.
(c) In regions where there is no applied voltage the liquid crystal rotates the plane of polarization so light is now transmitted by the analyser. In regions where there is voltage applied the liquid crystal molecules align with the electric field and no longer rotate the plane of polarization. The observer would see a dark circle surrounded by light.
- 3** The halogen atoms have a larger mass and so C—X bonds vibrate at a lower frequency.

Answers

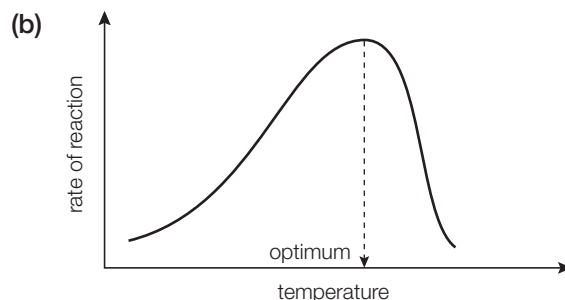
Chapter 13

Exercises

- 1 $C_{18}H_{32}O_{16} + 2H_2O \rightarrow 3C_6H_{12}O_6$
- 2 Monomers must each have two functional groups. A molecule of water is given off for each bond that forms between the monomers.
- 3 (a) anabolic (b) catabolic
(c) catabolic (d) anabolic
- 4 Sunlight, photosynthetic pigments to absorb light energy, water and carbon dioxide.
Carbon dioxide is reduced by the hydrogen from water, forming carbohydrate. The oxidation state of carbon decreases from +4 in CO_2 to 0 in $C_6H_{12}O_6$. Oxygen is oxidized from -2 in H_2O to 0 in O_2 .
- 5 Aerobic respiration yields a great deal more energy than anaerobic respiration, as in the presence of oxygen the oxidation of glucose to CO_2 and H_2O is complete. In anaerobic respiration, oxidation is incomplete, and much of the energy remains in the end products such as ethanol.
- 6 C
- 7 (a) Tyr—Val—His; Tyr—His—Val; His—Tyr—Val; His—Val—Tyr; Val—His—Tyr; Val—Tyr—His
There are six different tripeptides possible from three amino acids: $3 \times 2 \times 1$
(b) There are 24 different peptides that can be synthesized from four amino acids: $4 \times 3 \times 2 \times 1$
- 8 (a) leucine (b) threonine
(c) glutamic acid (d) lysine
- 9 Fibrous proteins are usually elongated molecules with a well-defined secondary structure. They are structural materials and insoluble in water.

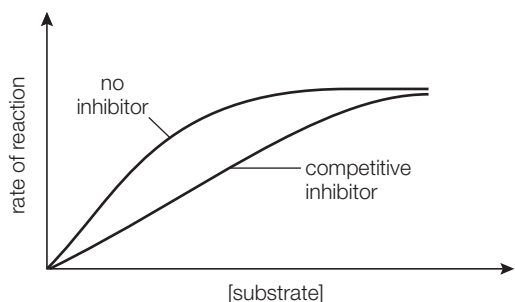
Globular proteins have a well-defined tertiary structure and are compact spherical molecules, soluble in water. They are functional as enzymes, carriers, hormones and receptors.

- 10 Hydrogen bonds in the secondary structure are between groups that are part of the peptide bonds of amino acids four residues apart in a polypeptide chain. Hydrogen bonds in the tertiary structure are between groups such as -OH in the side chains of amino acids.
- 11 (a) Enzymes are biological catalysts; they are made of proteins; they are very specific in their action; they are affected by changes in temperature and pH; during the reaction they form an enzyme–substrate complex in which the reaction occurs.



The shape shows increasing rate with increasing temperature as a result of the increase in average kinetic energy leading to more successful collisions between enzyme and substrate. This continues to a maximum point (close to 40 °C in humans), known as the optimum. At temperatures higher than this, the rate of the reaction falls dramatically as the enzyme is denatured. This means that it loses its specific tertiary structure and can no longer bind the substrate at the active site.

12



- 13 *Similarities:* both increase rate of reaction by providing pathway of lower E_a ; both have no effect on K_c or yield.

Differences: enzymes are proteins, inorganic catalysts have a varied structure; enzymes show saturation kinetics, inorganic catalysts usually do not; enzymes are regulated by inhibitors, inorganic catalysts are usually not; enzymes are sensitive to pH and temperature, inorganic catalysts usually work well at a wide range of temperature and pressure.

- 14 (a) Hands are likely to carry free amino acids that could be deposited on the paper and interfere with the chromatogram.
- (b) Isoleucine has an isoelectric point = 6.0
Therefore, at $\text{pH} < 6.0$ it will be positively charged and so attracted to the cathode; at $\text{pH} > 6.0$ it will be negatively charged and so attracted to the anode.
- (c) Glutamic acid has an isoelectric point = 3.2
Histidine has an isoelectric point = 7.6
Therefore, pH between 3.2 and 7.6 would achieve separation, e.g. pH 5.0.
Glutamic acid will be negatively charged and attracted to the anode.
Histidine will be positively charged and attracted to the cathode.

$$15 \quad 10.16 \text{ g I}_2 = \frac{10.16}{254} \text{ moles I}_2 \\ = 0.04 \text{ moles I}_2$$

Therefore, 0.02 moles fat react with 0.04 moles I_2 so there are two double bonds in the fat.

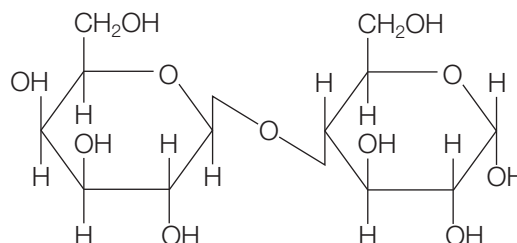
16 B

17 Fats and oils; hydrolytic and oxidative rancidity.

18 (a) CH_2O

- (b) Monosaccharides are water soluble as they are small molecules with many free $-\text{OH}$ groups which can form hydrogen bonds. Polysaccharides are insoluble as they are much larger molecules.

19



Lactose

$\text{C}_{12}\text{H}_{22}\text{O}_{11}$. Glycosidic bond.

- 20 (a) Carbon—carbon double bonds and hydroxyl groups.

- (b) Water-soluble: vitamin C; fat-soluble vitamin A / vitamin D.

Vitamin C has many $-\text{OH}$ and polar groups able to form hydrogen bonds with water. Vitamins A and D are predominantly non-polar/have hydrophobic groups and so cannot form hydrogen bonds with water.

- 21 Fortification of certain staple foods such as rice and flour with micronutrients; supply of nutritional supplements particularly in places where certain deficiencies are known (e.g. iodine); possible changes and improvements in nutrient content through genetic modification.

- 22 Ionic bonds, hydrogen bonds, London dispersion forces, hydrophobic interactions.

- 23 Biomagnification refers to the increasing concentration of a xenobiotic substance at different levels in a food web. It is often associated with toxic effects for organisms that feed at a high trophic level, as their cells contain the highest concentrations.

- 24 Break down oil spills, help break down some plastics, in biological detergents that improve energy efficiency, in Green Chemistry involving less toxic chemical pathways and solvents.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 (a) Melting point above 25 °C: lauric, myristic, palmitic and stearic acids are solids at room temperature. [2]
 (b) Melting point increases as van der Waals forces increase with size of the R group, due to an increase in number of electrons. [3]
 (c) An increase in the number of the C=C double bonds adds kinks to the structure, which reduces the ability of the molecules to pack together. The intermolecular forces are weaker and the melting points decrease. [3]

2 B 3 D 4 C 5 D

- 6 (a) condensation
 water / H₂O [2]
 (b)
$$\begin{array}{ccccccc} \text{H}_2\text{N} & -\text{CH}- & \text{CO}- & \text{NH}- & \text{CH}- & \text{COOH} & \\ & | & & & | & & \\ & \text{CH}_2-\text{SH} & & & \text{CH}_2-\text{OH} & & \\ & & & & & & \\ \text{H}_2\text{N} & -\text{CH}- & \text{CO}- & \text{NH}- & \text{CH}- & \text{COOH} & \\ & | & & & | & & \\ & \text{CH}_2-\text{OH} & & & \text{CH}_2-\text{SH} & & \end{array}$$
 [2]

- (c) Arg—His—Leu
 Arg—Leu—His
 His—Arg—Leu
 His—Leu—Arg
 Leu—Arg—His
 Leu—His—Arg [3 max]

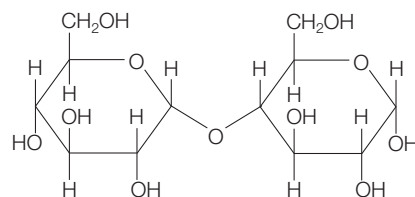
Award [3] for all six correct, [2] for five or four, [1] for three.

- (d) (i) hydrogen bonding [1]
 (ii) van der Waals forces / hydrophobic interactions / dispersion forces
 ionic bonding / (formation of) salt bridges / electrostatic attractions
 covalent bonding / (formation of) disulfide bridges [2 max]

Award [1] each for any two.

Do not accept sulfur bridges or hydrogen bonding.

- 7 (a) (i) [3]



- (ii) $\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \rightarrow 2\text{C}_6\text{H}_{12}\text{O}_6$ [2]

- (iii) catabolism [1]

Accept hydrolysis.

- 8 (a) rate of reaction increases with temperature from approximately 0 to 35°C
 increasing kinetic energy of enzyme and substrate increases the probability of a successful collision forming an enzyme–substrate complex
 catalytic action / alternative pathway of lower activation energy occurs due to binding of substrate to enzyme
 at 40°C tertiary structure / conformation of enzyme starts to break down / denature and less enzyme–substrate complex forms
 above 40°C enzyme is denatured / unable to bind to substrate [5]
 (b) optimum temperature / maximum rate of reaction at temperature lower than 40°C
 graph rises more quickly at low temperatures [2]

- 9 (a) (i) linoleic acid C₁₇H₃₁COOH so has two C=C bonds
 2 moles I₂ react with 1 mole linoleic acid
 2 × 254 g react with 280 g
 100 g linoleic acid reacts with $\frac{508 \times 100}{280}$
 = 181 g I₂ [3]

- (ii) X has fewer C=C double bonds / is less unsaturated / more saturated [1]

- (iii) X has higher melting point as molecules pack more closely
 unsaturation puts kinks in the hydrocarbon chains / less close packed / weaker intermolecular forces [2]

- (b) Hydrolytic rancidity: fat breaks down by hydrolysis at the ester links between glycerol and fatty acids, releasing the free acids.

Favoured by high temperature and enzyme lipase. [3]

Oxidative rancidity: unsaturated fat is oxidized at the carbon—carbon double bonds forming volatile aldehydes and ketones. Favoured by light and enzymes or metal ions. [3]

- (c) Lipids release more energy per unit mass on oxidation than carbohydrates, as they are more reduced. Lipids are insoluble and difficult to transport so their breakdown is more difficult and slower than carbohydrates. [3]

- 10 (a) substance foreign to organisms / not naturally found in the environment [2]

- (b) starch absorbs water and swells, causing plastic to break into small pieces which can be broken down by bacteria [2]

- (c) PVC contains the C—Cl bond for which no enzyme exists in the environment [2]

- 11 (specific) a particular enzyme can catalyse only one reaction
enzyme binds to/reacts with substance / $E+S \rightarrow ES$
after reaction product leaves enzyme / $EP \rightarrow E+P$
mention of active site [4]
OWTTE

Challenge yourself

- 1 The entropy of the environment increases. Energy is returned as less useful forms such as heat and other forms which quickly become randomized. Order is created at the expense of the environment, which becomes more disordered.
- 2 In $C_6H_{12}O_6$ the oxidation state of C = 0
In CO_2 the oxidation state of C = +4
- 3 Threonine and isoleucine have two chiral carbon atoms.
- 4 Proline is a secondary amine; all other amino acids are primary amines. In peptides, proline does not have any hydrogens bonded to N, so cannot be a hydrogen bond donor, but can be a hydrogen bond acceptor. The presence of proline leads to a bend or kink in the polypeptide chain.
- 5 Oxidation state of carbon will be higher in a carbohydrate than in a lipid, e.g. glucose and palmitic acid.

Answers

Chapter 14

Exercises

- 1 (a) Solar heating, solar electricity, hydroelectricity, wind power, biomass.
 (b) Fossil fuels.
 (c) Tidal is due to the presence of the moon, nuclear fission due to presence of radioactive elements found in the earth.
 (d) Renewable sources are generally derived from recent solar energy.
- 2 (a) $\frac{\text{useful output energy}}{\text{total input energy}} = \frac{\text{useful heat energy}}{\text{total input heat energy}} = 0.85$
 Heat energy produced by combustion = $4.00 \times 10^7 \text{ kJ} / 0.85$
 = $4.71 \times 10^7 \text{ kJ}$
 Moles of CH_4 = $4.71 \times 10^7 / 891 = 5.28 \times 10^4 \text{ mol}$
 Mass = $5.28 \times 10^4 \text{ mol} \times 16.05 \text{ g mol}^{-1}$
 = $8.48 \times 10^5 \text{ g} = 8.48 \times 10^2 \text{ kg}$
- (b) Energy produced by combustion = $4.00 \times 10^7 \text{ kJ} / 0.5$
 = $8.00 \times 10^7 \text{ kJ}$

Moles of CH_4 = $8.00 \times 10^7 / 891 = 8.98 \times 10^4 \text{ mol}$

Mass = $8.98 \times 10^4 \text{ mol} \times 16.05 \text{ g mol}^{-1}$
 = $1.44 \times 10^6 \text{ g} = 1.44 \times 10^3 \text{ kg}$

3 (a)

Formula	$M / \text{g mol}^{-1}$	$\Delta H_c / \text{kJ mol}^{-1}$	Specific energy / kJ g^{-1}
H_2	$= 2 \times 1.01$ $= 2.02$	-286	$= 286 / 2.02$ $= 142$
CH_4	$= 12.01 + (4 \times 1.01)$ $= 16.05$	-891	$= 891 / 16.05$ $= 55.5$

(b) Assuming ideal behaviour: $PV = nRT$

$$PV = (m/M)RT$$

$$\rho = m/V = PM/RT$$

With everything in SI units, the units of density are kg m^{-3}

With the molar mass in g mol^{-1} , the units of density are g m^{-3}

STP conditions: $T = 273 \text{ K}$ and $P = 100 \text{ kPa}$

3 (b)
cont'd

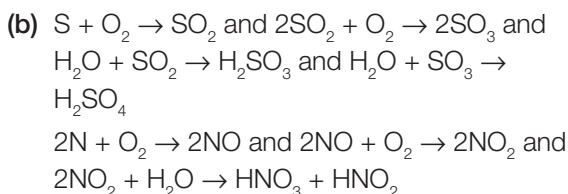
Formula	Specific energy / kJ g^{-1}	Density / g m^{-3}	Energy / kJ cm^{-3}
H_2	$= 286 / 2.02$ $= 142$	$= 1.00 \times 10^5 \times 2.02 / 8.13 \times 273$ $= 91.0$	$= (286 / 2.02) \times 1.00 \times 10^5 \times 2.02 / (8.13 \times 273)$ $= 12900$
CH_4	$= 891 / 16.05$ $= 55.5$	$= 1.00 \times 10^5 \times 16.05 / 8.13 \times 273$ $= 723$	$= (891 / 16.05) \times 1.00 \times 10^5 \times 16.05 / (8.13 \times 273)$ $= 40100$

Note: energy density of a gas is not determined by the molar mass.

- 3 (c) Hydrogen is the best fuel.

It is dangerous to store and burn.

- 4 (a) Empirical formula: $C_{135}H_{96}O_9NS$. (It typically also contains trace elements of silicon, sodium, calcium, aluminium, nickel, copper, zinc, arsenic, lead and mercury.)



5 (a)
$$\frac{\text{useful output energy}}{\text{total input energy}} = \frac{\text{useful heat energy}}{\text{total input heat energy}} = 0.38$$

Heat energy produced by combustion =

$$5.00 \times 10^5 \text{ kJ s}^{-1} / 0.38$$

$$\text{Mass} = 5.00 \times 10^5 \text{ kJ s}^{-1} / (0.38 \times 33.0 \text{ kJ g}^{-1})$$

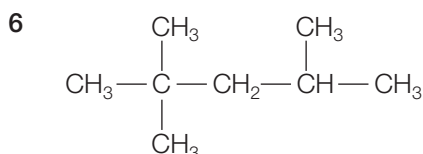
$$= 39\,900 \text{ g s}^{-1} = 39.9 \text{ kg s}^{-1}$$

- (b) We have the unbalanced equation: $CH + (5/4)O_2 \rightarrow CO_2 + \frac{1}{2}H_2O$

no. of moles of CO_2 = no. of moles of CH

$$\text{no. of moles of C H} = 39\,900 / (12.01 + 1.01) = 3062 \text{ mol}$$

$$\text{mass of } CO_2 = 3062 \times 44.01 = 135\,000 \text{ g} = 135 \text{ kg}$$



- 7 (a) $C_{11}H_{24} \rightarrow C_2H_6 + 3C_3H_6$ or $C_{11}H_{24} \rightarrow C_5H_{12} + 3C_2H_4$

- (b) Increases the yield of the more useful lower fractions used as fuels for cars.

Produces the more reactive alkenes, which can be used as chemical feedstock, to make useful products such as plastics.

- (c) Lower temperatures needed. Catalysts act selectively, increasing the yield of the desired product.

- 8 (a) Octane is one of the main components of petroleum: C_8H_{18}

Any compound between pentane and decane would be acceptable as an answer.

- (b) They are isolated from crude oil by fractional distillation.

- The mixture of hydrocarbons is heated, causing them to vaporize.
- As the vapour travels up the fractionating column the hydrocarbons condense at different heights, resulting in their separation.
- The different compounds have different boiling points: the lowest boiling point compounds condense at the top and the highest boiling point compounds condense at the bottom.
- As the relative molar mass increases, the attractive London dispersion forces between the molecules increase, leading to an increase in the boiling point.

- (c) The components of gasoline have boiling points above normal temperatures. They are volatile liquids.

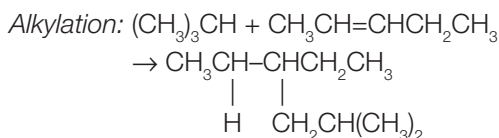
They can be easily vaporized in the car cylinder for reaction with oxygen.

Lower molar mass compounds are gases which occupy too much volume, while higher molar mass compounds do not vaporize or burn easily.

- (d) Higher fractions can be cracked into smaller molecules; the larger molecules are heated with a catalyst and broken into smaller molecules.

Alkenes formed in the cracking process can undergo alkylation reactions with lower molecular mass alkanes to further increase the yield of gasoline.

- (e) *Cracking*: $C_{16}H_{34} \rightarrow C_6H_{12} + C_{10}H_{22}$
 $C_6H_{10} + C_{10}H_{24}$



- 9 The general pattern is:
straight-chain alkanes < cycloalkanes < alkenes < aromatics
pentane < cyclopentane < pentene < benzene
- 10 The general pattern is that the octane number of straight-chain alkanes decreases with an increase in chain length. Alcohols have very high octane numbers.
heptane < hexane < pentane < ethanol
- 11 (a) High specific energy / energy density.
As a liquid it is convenient to handle and deliver.
Easy to vaporize, which assists combustion.
(b) It is formed by the partial decomposition of marine plants millions of years ago.
(c) Compounds are separated by fractional distillation.
Increase of petrol fraction by cracking.
Further refining: reforming, alkylation, isomerization to increase octane number.
- 12 *Coal gasification*
 $\text{C(s)} + \text{H}_2\text{O(g)} \rightarrow \text{CO(g)} + \text{H}_2\text{(g)}$
 $\text{CO(g)} + 3\text{H}_2\text{(g)} \rightarrow \text{CH}_4 + \text{H}_2\text{O}$
Coal liquefaction
Direct: $5\text{C(s)} + 6\text{H}_2\text{(g)} \rightarrow \text{C}_5\text{H}_{12}\text{(l)}$
 $11\text{H}_2\text{(g)} + 5\text{CO(g)} \rightarrow \text{C}_5\text{H}_{12}\text{(l)} + 5\text{H}_2\text{O(l)}$
- 13 Carbon-containing fuels are non-renewable.
They are needed as chemical feedstocks.
Their combustion adds carbon dioxide to the atmosphere, which contributes to global warming.
- 14 (a) $\text{CO(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}: \Delta H_c^\ominus = -283 \text{ kJ mol}^{-1}$
 $\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O(g)}: \Delta H_c^\ominus = -286 \text{ kJ mol}^{-1}$
 $\text{CO(g)} + \text{H}_2\text{(g)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)} + \text{H}_2\text{O(g)}:$
 $\Delta H_c^\ominus = -283 + (-286) \text{ kJ mol}^{-1} = -569 \text{ kJ mol}^{-1}$
(b) $\text{CH}_4\text{(g)} + 2\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)} + 2\text{H}_2\text{O(g)}:$
 $\Delta H_c^\ominus = -891 \text{ kJ mol}^{-1}$
- (c) One mole of synthesis gas has the same volume as two moles of methane. One mole of synthesis gas produces 569 kJ and two moles of methane produce $2 \times 891 \text{ kJ}$.
- 15 (a) Methane is the major component of natural gas. It has the formula CH_4 .
 $\text{CH}_4\text{(g)} + 2\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)} + 2\text{H}_2\text{O(g)}$
(b) Natural gas is the cleanest of the fossil fuels to burn as it has a high H : C ratio.
The combustion of natural gas produces minimal amounts of carbon monoxide, hydrocarbons and particulates. It does contribute to global warming but does not contribute to acid rain, unlike coal and oil.
(c) Natural gas is the fossil fuel in the shortest supply and it is unevenly distributed around the world.
Oil is expected to last a little longer and coal, which is distributed more evenly around the world, longer still.
(d) Supplies of methane can be increased as a result of the cracking of larger hydrocarbons from oil or by coal gasification.
- Cracking*
 $\text{C}_4\text{H}_{10} \rightarrow \text{CH}_4\text{(g)} + \text{C}_3\text{H}_6\text{(g)}$
Coal gasification
 $\text{C(s)} + \text{H}_2\text{O(g)} \rightarrow \text{CO(g)} + \text{H}_2\text{(g)}$
 $\text{CO(g)} + 3\text{H}_2\text{(g)} \rightarrow \text{CH}_4 + \text{H}_2\text{O}$
- 16 (a) Wide availability
Relatively cheap compared to other sources
Ease of transportation
Power stations can be built close to the source
High energy density
Can be used with existing technology
Concern over nuclear
Limited productivity of other sources
Not possible to generate sufficient electrical energy without it
Many transport systems rely on fossil fuels
(b) Oil used to power internal combustion engines

17 It is more efficient

It produces more thermal energy per unit of mass / has a higher specific energy / energy density

It produces less CO₂ per unit of output energy

18 (a)

Fuel	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$	Moles needed to produce 10 000 kJ	Molar mass / g mol ⁻¹	Mass needed to produce 10 000 kJ
Methylbenzene	-3910	10 000/3910 = 2.56	(12.01 × 7) + (8 × 1.01) = 92.15	2.56 × 92.15 = 236
Ethanol	-1367	10 000/1367 = 7.31	(12.01 × 2) + (6 × 1.01) + 16.00 = 46.08	7.31 × 46.08 = 337

(b)

Fuel	Moles of CO ₂ produced / mol	Mass of CO ₂ produced / g
Methylbenzene	7 × 2.56 = 17.92	17.92 × 44.01 = 789
Ethanol	2 × 7.31 = 14.62	14.62 × 44.01 = 643

18 (c) They produce less carbon dioxide / have a smaller carbon footprint.

19 (a) ${}_0^1\text{n}$

(b) ${}_8^{17}\text{O}$

20 (a) $\Delta E = hc/\lambda$

$$\begin{aligned}
 &= 6.63 \times 10^{-34} \times 3.00 \times 10^8 / \lambda \text{ J} \\
 &= 6.02 \times 10^{23} \times 6.63 \times 10^{-34} \times 3.00 \times 10^8 / \lambda \text{ J mol}^{-1} \\
 &= 6.02 \times 10^{20} \times 6.63 \times 10^{-34} \times 3.00 \times 10^8 / \lambda \text{ kJ mol}^{-1} \\
 &= 0.00012 / \lambda \text{ kJ mol}^{-1}
 \end{aligned}$$

λ / m	$\Delta E / \text{kJ mol}^{-1}$
656×10^{-9}	$0.00012 / 656 \times 10^{-9}$ = 183
486×10^{-9}	$0.00012 / 486 \times 10^{-9}$ = 247
434×10^{-9}	$0.00012 / 434 \times 10^{-9}$ = 276

(b) By inspection we can see that transitions from $n = 2$ fall into this range

$\Delta E / \text{kJ mol}^{-1}$	Transition
183	$n = 2 \rightarrow n = 3$
247	$n = 2 \rightarrow n = 4$
276	$n = 2 \rightarrow n = 5$

(c) At higher energy, energy levels become closer together; the energy differences between higher energy levels and the lower level ($n = 2$) become closer together and the difference in wavelength decreases.

21 (a) W: atomic number = 90, mass number = 233 - 4 = 229: ${}_{90}^{229}\text{Th}$

X: atomic number = 0, mass number = 236 - 233 = 3: ${}_0^3\text{n}$

Y: atomic number = 93, mass number = 239: ${}_{93}^{239}\text{Np}$

Z: atomic number = 34, mass number = 92: ${}_{34}^{92}\text{Se}$

(b) Process II (fission) is used to produce electricity in nuclear power plants. (Process IV is also a fission reaction and is another potential reaction.)

This process can be initiated as required by controlling the input of neutrons, whereas

the other processes are natural ones and occur randomly.

Process II is self-sustaining if the critical mass is available. It produces more neutrons than are needed initially and so a chain reaction occurs which can lead to the fission of more nuclei.

- (c) The mass of the products is less than the mass of the reactants. The difference is converted to energy according to the equation $\Delta E = \Delta mc^2$.

- 22 Less than 1% of uranium is the fissionable isotope: $^{235}_{92}\text{U}$

There is less than the critical mass present.

There is insufficient $^{235}_{92}\text{U}$ to sustain the chain reaction.

23 (a)

Time / half-lives	Fraction remaining
0	1
1	0.5
2	0.25
3	0.125
4	0.0625
5	0.03125
6	0.015625
7	0.0078125
8	0.00390625
9	0.001953125
10	0.000976563

- (b) 99.9%

- 24 First notice that $96.0 \text{ s} = 96.0/19.2 = 5t_{1/2}$

Use the information in the question to compile a table:

Time / half-lives	Time / s	Activity / s^{-1}
0	0	1200
1	19.2	600
2	38.4	300
3	57.6	150
4	76.8	75
5	96.0	37.5

The count rate would be 37 or 38 disintegrations per second.



- 26 High level: contains fission products
Low level: clothing / fuel cans / other
Stored under water
Buried underground
Encased in steel/concrete
Vitrified / made into glass

- 27 Use the information in the question to compile a table:

Time / years	Activity / $\text{hr}^{-1} \text{ g}^{-1}$
0	60.0
5730	30.0
5730×2	15.0
5730×3	7.5
5730×4	3.75

The shell is approximately 5730×4 years = 22 920 years old.

- 28 (a) $\text{CH}_2=\text{CH}-\text{CH}=\text{CH}_2$ is a conjugated system with two double bonds separated by a single bond which extends along the full length of the molecule.
(b) The double bonds disappear as the molecules undergo an addition reaction with bromine.
(c) Benzene absorbs radiation in the UV region.
In nitrobenzene, conjugation between the benzene ring and the nitro group allows radiation of longer wavelength to be absorbed. This radiation occurs in the visible region of the spectrum and so the compound is coloured.
- 29 (a) Increased conjugation (increased n) moves the absorption band λ_{max} towards longer wavelength.
(b) The first members of the series are colourless as they absorb in the UV region, but the later members ($n > 2$) are coloured as they absorb in the visible region.
(c) $\text{C}_6\text{H}_5-(\text{CH}=\text{CH})_5-\text{C}_6\text{H}_5$ absorbs in the purple region and is probably yellow.

$\text{C}_6\text{H}_5-(\text{CH}=\text{CH})_6-\text{C}_6\text{H}_5$ absorbs in purple/blue region and is probably orange.

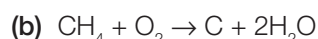
- (d) Only λ_{max} and not the full spectrum is given so it is not possible to give a precise answer.
- 30 The conjugated system includes eleven $\text{C}=\text{C}$ bonds and so absorbs in the visible region. The molecule absorbs blue light and so appears orange.
- 31 (a) Fossil fuels and biomass are derived from the sun through photosynthesis.
Other sources: wind and hydroelectricity.
(b) Advantage: renewable and has little environmental impact.
Disadvantages: photosynthesis is not very efficient so relatively little of the available solar energy is trapped.
- 32 (a) $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
(b) Chlorophyll
(c) Conjugated system of double and single bonds
(d) Process: fermentation
Equation: $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2$
Conditions: acidity / absence of oxygen / below 40°C
Yeast provides enzyme
- 33 (a) Methane
(b) Carbon monoxide and hydrogen
(c) Particulates (soot), hydrocarbons, carbon monoxide
(d) Fossil fuels are running out. Biomass is a renewable source.
- 34 (a) 1%
(b) Wavelength of radiation not absorbed by chlorophyll
Some radiation is reflected or heats the surface of the earth
Plants do not cover all the earth
(c) Photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
(d) Production of biogas
Production of ethanol / fermentation
- 35 Biodiesel is renewable.
Biodiesel is carbon neutral. Plants use the same amount of CO_2 to make the oil that is released when the fuel is burned.
Biodiesel is rapidly biodegradable and completely non-toxic, meaning spillages represent far less risk than petroleum diesel spillages.
Biodiesel has a higher flash point than petroleum diesel, making it safer in the event of a crash.
Blends of 20% biodiesel with 80% petroleum diesel can be used in unmodified diesel engines. Biodiesel can be used in its pure form but engines may require certain modifications to avoid maintenance and performance problems.
Biodiesel can be made from recycled vegetable and animal oils or fats.
- 36 (a) Distant from localized areas of pollution; data present an accurate measure of global levels of CO_2 .
(b) % increase = (increase/initial value) $\times 100\%$
= $[(384 - 316)/316] \times 100\% = 21.5\%$
(c) Combustion of fossil fuels.
(d) The annual variation is due to CO_2 uptake by growing plants. The uptake is highest in the northern hemisphere springtime.
(e) Photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
 CO_2 dissolves in water: $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
(f) Decreased level of photosynthesis: less CO_2 taken in by plants.
(g) CO_2 absorbs infrared radiation, which leads to increased vibrations and bending and stretching of the bonds.
- 37 (a) Carbon dioxide has polar $\text{C}=\text{O}$ bonds and the oxygen atoms have lone pairs. It can form hydrogen bonds with water molecules.
(b) Relatively strong hydrogen bonds are formed: ΔH is negative. The solubility decreases with increasing temperature, as the equilibrium shifts to the endothermic (reverse) direction as the temperature increases.

- (c) Increased temperatures due to increased atmospheric carbon dioxide concentrations could result in reduced solubility of carbon dioxide. More carbon dioxide is then released, which amplifies the initial change.
- (d) Increased carbon dioxide increases the rate of photosynthesis, producing more phytoplankton, which further reduce levels of carbon dioxide.
- 38 The removal of $\text{CO}_3^{2-}(\text{aq})$ will cause the equilibrium $\text{HCO}_3^-(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$ to shift to the right. The resulting decreased levels of $\text{HCO}_3^-(\text{aq})$ will cause $\text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$ to shift to the right and so on until $\text{CO}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{aq})$ shifts to the right with the absorption of $\text{CO}_2(\text{g})$.
- 39 $\text{pH} = 8.2: [\text{H}^+] = 10^{-8.2}$
 $\text{pH} = 8.1: [\text{H}^+] = 10^{-8.1}$
 $\% \text{ increase} = (10^{-8.1} - 10^{-8.2}) / 10^{-8.2} \times 100\%$
 $= (10^{0.1} - 1) \times 100\% = 26\%$
- 40 (a) Respiration, volcanic eruption, complete aerobic decomposition of organic matter, forest fires
- (b) Methane produced from anaerobic decomposition
- (c) Smoke particulates: block out sunlight
- (d) High-energy short-wavelength radiation passes through the atmosphere
 Lower energy / longer wavelength radiation from the earth's surface is absorbed by vibrating bonds in CO_2 molecules
- (e) Melting of polar ice caps; thermal expansion of oceans will lead to rise in sea levels, which can cause coastal flooding; crop yields reduced; changes in flora and fauna distribution; drought; increased rainfall; desertification
- 41 (a) Incoming radiation from the sun is of short wavelength
 Long-wavelength infrared radiation leaves earth's surface and some is absorbed by gases in the atmosphere

Results in increased vibration of bonds in molecules which then re-radiate heat back to the earth

- (b) *Natural:* (evaporation from) oceans
Artificial: burning (any specified) fossil fuel
- (c) CO_2 is more abundant but CH_4 absorbs the radiation more effectively / has a larger greenhouse factor

42 (a) coal / diesel (fuel) / wood



Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 (a) long wavelength / infrared / IR radiation from Earth's surface
 (some of this radiation) is absorbed (by gas)
Do not accept 'trapped' or 'blocked'.
Do not award mark for 'IR from sun'.
 causes (increased) vibration in bonds
 re-radiates heat back to the Earth
Accept 're-transmits'
Do not accept 'reflects/bounces' [2 max]
- (b) melting of polar ice caps / glaciers melting
 thermal expansion of oceans / rise in sea levels / coastal flooding
 stated effect on agriculture (e.g. crop yields changed)
 changes in flora / plant / fauna / animal / insect distribution / biodiversity
Accept specific example.
 stated effect on climate (e.g. drought / increased rainfall / desertification)
Do not accept 'climate change' alone.
Do not allow 'increased temperature / global warming' (given in question).
Award [1] each for any three. [3 max]
- 2 high-level waste has longer half-life / low-level waste has shorter half-life

high-level waste is vitrified / made into glass / buried underground / in granite / in deep mines / under water / in steel containers / in cooling ponds / OWTTE

low-level waste is stored under water / in steel containers / in cooling ponds / filtered / discharged directly into sea / OWTTE

Accept cooling ponds/steel containers/under water/concrete containers only once. [3]

3 Catalytic cracking:

used to produce moderate length alkanes for fuels

lower temperature / lower energy consumption / more control of product [2]

4 light nuclei for fusion and heavy nuclei for fission

more massive nucleus produced in fusion as nuclei joined together and two lighter nuclei produced in fission as nuclei split apart [2]

5 6.25% remains

4 half-lives = 6400 years [2]

6 (a) energy transferred to surroundings / from system which is no longer available for use / cannot be used again [2]

(b) $^{235}_{92}\text{U}$ undergoes a fission reaction due to neutron capture

reaction produces neutrons so chain reaction occurs

mass of products less than reactants

corresponding energy released according to $E = mc^2$ [4]

(c) the mass needed that allows fission to be sustained [1]

7 (a) wide availability

produce energy at appropriate rate

ease of transportation

current technology is based on fossil fuels

high energy density / specific energy [2 max]

(b) energy produced per unit mass / kg / stored per unit mass / kg [1]

(c) uranium / hydrogen [1]

(d) Efficiency = $600 \times 10^6 / \text{energy}_{\text{input}}$

$$\text{Energy}_{\text{input}} = 600 \times 10^6 / 0.30 \text{ J s}^{-1} = 2000 \times 10^6 \text{ J s}^{-1}$$

$$\text{Mass of fuel} = 2000 \times 10^6 / 60 \times 10^3 = 33.3 \times 10^3 \text{ g s}^{-1} \quad [3]$$

8 (a) coal about 90% and petroleum about 84% and natural gas 75% [1]

(b) they have higher specific energy

liquid or gaseous state make them more convenient to use / easier to transport

produce less pollution / smaller carbon foot print [2 max]

(c) hydrogen has a very high specific energy / energy density

it is clean burning producing only H_2O when it is burned [2]

9 (a)

Formula	$M / \text{g mol}^{-1}$	$\Delta H_c / \text{kJ mol}^{-1}$	Specific energy / kJ g^{-1}
C_3H_8	44.11	-2219	$2219/44.11 = 50.31$
C_4H_{10}	58.14	-2878	$2878/58.14 = 49.50$

[2]

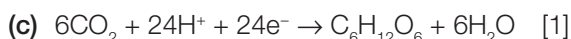
(b) $\rho = PM/RT$

Formula	Specific energy
C_3H_8	$(2219/44.11) \times 1.00 \times 10^5 \times 44.11 / (8.13 \times 273)$ $= 2219 \times 1.00 \times 10^5 / (8.31 \times 273)$ $= 97800 \text{ kJ m}^{-3}$ $= 0.978 \text{ kJ cm}^{-3}$
C_4H_{10}	$(2878/58.14) \times 1.00 \times 10^5 \times 58.14 / (8.13 \times 273)$ $= (2878 \times 1.00 \times 10^5) / (8.31 \times 273)$ $= 127000 \text{ kJ m}^{-3}$ $= 0.127 \text{ kJ cm}^{-3}$

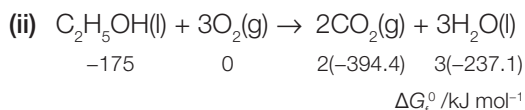
[3]

10 (a) photosynthesis [1]

(b) chlorophyll
conjugated structure [2]



(e) (i) fermentation



$\Delta G = 2(-394.4) + 3(-237.1) - (-175) = -1325.1 \text{ kJ mol}^{-1}$

thermodynamic efficiency =
 $-1325.1 / -1367 = 97\%$ [3]

11 (a) the octane number indicates the resistance of a motor fuel to knock / premature ignition
 octane numbers are based on a scale on which 2,2,4-trimethylpentane (isooctane) is 100 (minimal knock) and heptane is 0 (maximum knock) [2]

(b) octane number of straight-chain alkanes decrease with an increase in chain length
 straight chain alkanes < aromatics
 alcohols have very high octane numbers:
 hexane (24.8) < pentane (61.7) < benzene (105.8) < ethanol (108) [4]

The octane numbers are given for reference and are not expected to be recalled.

12 (a) ${}_{92}^{235}\text{U} \rightarrow {}_{90}^{231}\text{Th} + {}_2^4\text{He}$
 atomic number = 90 and element = Th
 mass number = 231 [2]

(b) To answer this question you need to know that the half-life of ${}_{92}^{235}\text{U}$ is 704 million years.
 After one half-life the amount of ${}_{92}^{235}\text{U}$ will have decayed to 50% of its original amount.
 After two half-lives the amount of ${}_{92}^{235}\text{U}$ will have decayed to 25% of its original amount, i.e. 75% will have decayed.

$2 \times 704 \text{ million years} = 1408 \text{ million years}$
 It will take 1408 million years for 75% of the ${}_{92}^{235}\text{U}$ to decay. [2]

13 (a) effects due to: increased carbon dioxide levels, global warming
 non-metal / sulfur / nitrogen oxides produce acid rain
 unburned hydrocarbons and carbon monoxide
 particulates cause global dimming [3 max]

13 (b)

Strategy	Action
Increased energy efficiency and conservation	<ul style="list-style-type: none"> Use of insulation and more efficient appliances Reducing personal energy use by turning off lights and electronics when not in use Reducing distance travelled in vehicles or using more efficient modes of transport such as hybrid cars or public transport Award [1 max] for action
Reduced dependence on carbon-based energy resources	<ul style="list-style-type: none"> Use alternative sources such as solar, wind, geothermal, hydropower, wave, tidal or nuclear power Use reduced-carbon fuels such as natural gas. The potential use of biomass depends on the processes by which it is converted to energy Award [1 max] for action
Capture and storage of carbon from fossil fuels or from the atmosphere	<ul style="list-style-type: none"> Carbon dioxide can be removed from the atmosphere and stored within plants and soil supporting the plants. Alternatively, carbon dioxide can be captured either before or after fossil fuel is burned and then be stored (sequestered) within the earth Reduce deforestation and plant more trees Award [1 max] for action

[6]

- (c) countries with cheaper gasoline on average:
use more gasoline
have less efficient vehicles
produce more CO₂ and have higher carbon footprint [3]

- 14 (a) octane C₈H₁₈
any other compound with C₅–C₁₀ [2]
- (b) fractional distillation
mixture of hydrocarbons is heated causing them to vaporize
different compounds have different boiling points; the lowest boiling point compounds condense higher up the column
as the size of the molecule increases the attractive van der Waals forces increase [4]
- (c) larger molecules can be cracked into smaller molecules when heated with a catalyst and broken into smaller molecules
equation for cracking: C₁₄H₃₀ → C₇H₁₄ + C₇H₁₆ [2]

15 (a)

Fuel	Formula	Standard enthalpy of combustion ΔH / kJmol ⁻¹	Relative molecular mass	Specific energy / kJ g ⁻¹
methane	CH ₄	-891	16.05	55.5
methanol	CH ₃ OH	-726	32.05	22.7

[2]

- (b) CH₄: Ox (C) = -4; CH₃OH: Ox (C) = -2 [1]
- (c) the more oxidized the C the lower the specific heat [1]

(d)

Fuel	Formula	Standard enthalpy of combustion ΔH / kJmol ⁻¹	Relative molecular mass	Specific energy / kJ g ⁻¹
methanol	C ₆ H ₁₂ O ₆	-2803	180.18	15.6

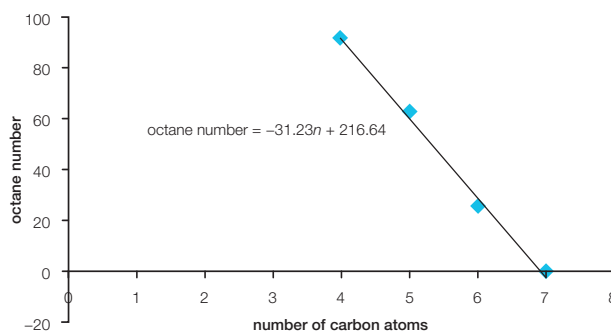
oxidation number of C = 0

the result supports the hypothesis [3]

- 16 (a) they are too viscous
as there are strong intermolecular forces between the triglyceride molecules [2]
- (b) transesterification
reaction with methanol or ethanol with strong acid or base catalyst produces a methyl / ethyl ester [2]

Challenge yourself

- 1 680 kJ of heat is given out. Energy efficiency is 32%.
- 2 Coal and oil are fossilized decayed plants or animals that contain amino acids. The amino acid *cysteine* contains sulfur. Coal and oil with a higher percentage of sulfur are considered 'dirty' because of the sulfur dioxide pollution that they produce on combustion. Sulfur dioxide results in acid rain.
- 3 (a) Plotting a graph we see that the data follow an approximate straight-line relationship:



This suggests an octane number of -33.

In practise the graph is a curve rather than a straight line and octane has an octane number of -19.

- (b) Assuming the same straight-line trend, for an octane number of 100, $n = 3.73$. So propane has an octane number above 100.
- 4 The isomers of octane have the essentially the same number of C—C and C—H bonds.
This suggests that they are not a key factor in a molecule's octane number.

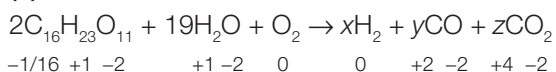
- 5 The ratio between the values is approximately 4
This corresponds to $2^2 = Z^2$, where Z is the atomic number of helium.

This is a general result: the energy level is proportional to the square of the atomic number.

- 6 $C_{40}H_{56}$

The position of the double bond in the hexagon on the right is different in the two isomers.

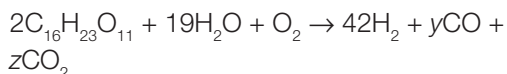
- 7 (a)



- (b) C is oxidized

O and H are reduced

- (c) Balancing the H atoms:



$$x = 42$$

- (d) Total change of oxidation number of H = -84

Total change of oxidation number of O = -2

Total increase in oxidation number of C = +86

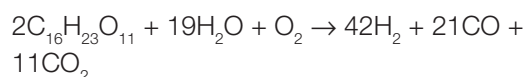
Balancing the change in oxidation numbers:

$$2y + 4z - 2 = +86$$

Balancing the C atoms: $y + z = 32$

Solving the equations: $2z = 88 - 64 = 22$

$$z = 11 \text{ and } y = 21$$



- (e) $42H_2 + 21CO \rightarrow 21CH_3OH$

2 molecules of wood produce 21 molecules of methanol

1 molecule produces 10.5 molecules

- 8 The solubility of carbon dioxide increases at lower temperatures and higher pressures.

Increased levels of $CO_2(g)$ will lead to the formation of the more soluble $Ca(HCO_3)_2(aq)$.



Chapter 15

Exercises

- 1 intramuscular / into muscles
intravenous / into veins
subcutaneous / into fat
The fastest will be intravenous as the drug can be transported quickly all over the body in the bloodstream.
- 2 Tolerance occurs when repeated doses of a drug result in smaller physiological effects. It is potentially dangerous because increasing doses of the drug are used in response and this might get close to or exceed the toxic level.
- 3 (a) Lethal doses can be determined for animals; in humans the upper limit is the toxic dose.
(b) Bioavailability, side-effects, possibility of tolerance and addiction of the drug; age, sex, diet and weight of patient.
(c) Low therapeutic index means a low margin of safety, so small changes in dosage may produce adverse side-effects.
- 4 Method of administration of drug, solubility (in water and lipid) and functional group activity.
- 5 (a) 84.94%
(b) melting point determination: melting point of aspirin is 138–140°C
- 6 Increase its solubility in water by converting to sodium salt.
- 7 (a) Mild analgesic blocks transmission of impulses at site of injury, not in the brain; anticoagulant acts to prevent coagulation / thickening of the blood and so reduces risk of coronary disease.
(b) Alcohol has synergistic effect with other drugs; can cause stomach bleeding with aspirin.
- 8 (a) $\text{R}-\text{C}_9\text{H}_{11}\text{N}_2\text{O}_4\text{S}$
(b) At the R group. Modification prevents the binding of the penicillinase enzyme and so maintains the action of the drug / prevents resistant bacteria rendering it inactive.
- (c) Beta-lactam ring undergoes cleavage and binds irreversibly to the transpeptidase enzyme in bacteria. This inactivates the enzyme, which interrupts the synthesis of bacterial cell walls.
- 9 Overuse of antibiotics in animal stocks / food chain; over-prescription; failure of patients to complete treatment regimen.
- 10 (a) The functional groups in common are ether linkage ($-\text{C}-\text{O}-\text{C}-$), tertiary amine linkage ($\text{R}-\text{N}(\text{R}')-\text{R}''$), alkenyl ($-\text{C}=\text{C}-$) and arene.
(b) main effect: pain relief
side-effect: constipation
- 11 Diamorphine has two ester groups in place of two $-\text{OH}$ groups in morphine. The less polar diamorphine is more soluble in lipids and so crosses the blood–brain barrier more easily, and enters the brain where it blocks the perception of pain.
- 12 In favour: strongest pain killer known; the only effective analgesic against extreme pain.
Against: addictive drug; leads to dependence and serious side-effects.
- 13 H_2 -receptor antagonists: block the binding of histamine, which prevents the reactions leading to stomach acid secretion.
Proton-pump inhibitors: directly prevent the release of acid into the stomach lumen.
- 14 (a) $\text{Mg}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$
 $\text{Al}(\text{OH})_3 + 3\text{HCl} \rightarrow \text{AlCl}_3 + 3\text{H}_2\text{O}$
(b) $\text{Al}(\text{OH})_3$ reacts with H^+ in a mole ratio of 1:3
 $\text{Mg}(\text{OH})_2$ reacts with H^+ in a mole ratio of 1:2
So 0.1 mol $\text{Al}(\text{OH})_3$ will neutralize the greater amount.

- (c) KOH is a strong alkali so would be dangerous for body cells; it is corrosive and would upset the stomach pH.
- 15 (a) 5.12.
(b) No change in pH on dilution of buffer.
- 16 Viruses lack a cellular structure and so are difficult to target. Antibiotics specifically interfere with bacterial cell walls or internal structures. Viruses replicate inside host cells and so treatment may involve killing host cells.
- 17 Subunits in hemagglutinin (H) and neuraminidase (N) can mutate and mix and match, so forming different strains. These change the specific nature of the glycoprotein–host interactions, and alter the body’s immune response. This is why it is possible to suffer from flu several times during a lifetime.
- 18 Tamiflu and Relenza do not prevent the flu virus from entering cells, but act to stop it from being released from the host cells. So if the infection is not stopped early, too many new viral particles may have already been released.
- 19 Challenges: antiretroviral costs, distribution and availability; patient compliance to regimen and multiple drug treatments; sociocultural issues.
Successes: new and more effective antivirals that can be used in combination; better screening of HIV-positive; controlling infection through drugs.
- 20 Solvents cause problems of disposal. Organic solvents can be incinerated, causing release of pollutants, greenhouse gases and toxins. Solvents can contaminate ground water and soil. Some solvents can be hazardous to health of workers.
- 21 Protective shoe-covers, clothing, gloves, paper towels and contaminated implements. Interim storage in sealed containers for radioactivity to decay, before conventional disposal.
- 22 The success of antibiotics in treating disease has led to their widespread use, and in some cases over-use. Exposure of bacteria to antibiotics

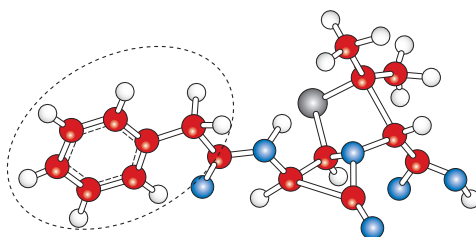
increases the spread of resistant strains. Antibiotic resistance renders some antibiotics ineffective, especially with multiply resistant strains, e.g. MRSA.

- 23 Patient compliance refers to the importance of patients following medical instructions, in particular to completing the course of an antibiotic treatment. This helps prevent the spread of antibiotic-resistant bacteria.
- 24 Green Chemistry principles seek to reduce toxic emissions and waste substances in the manufacture of drugs. This includes reduction in the amount of solvent used, the adoption of synthesis pathways with shorter routes, the replacement of inorganic catalysts with enzymes and the recycling of waste.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

- 1 C 2 B 3 D 4 B
5 C 6 C
7 (a)



[1]

No mark if circle includes CO or just O.

Award [1] if it includes 7 C atoms but misses out on attached H atoms

- (b) overprescription can lead to allergic reaction
may wipe-out harmless/helpful/beneficial bacteria (in the alimentary canal)/destroyed bacteria may be replaced by more harmful bacteria
(may pass on genetic) resistance/immunity
[1] each for any two.
modify R group/side chain to change penicillin effectiveness / form penicillin that

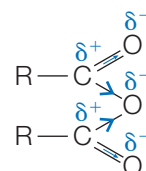
- is more resistant to penicillinase enzyme [3 max]
- 8 (a) $\text{Al}(\text{OH})_3 + 3\text{HCl} \rightarrow \text{AlCl}_3 + 3\text{H}_2\text{O}$ / $\text{Mg}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$ [1]
Accept ionic equations.
- (b) less effect **and** (magnesium hydroxide) 2/0.2 mol OH^- ions available as compared to (aluminium hydroxide) 3/0.3 mol OH^- ions for neutralization / neutralizes 2H^+ /0.2 mol acid as compared to 3H^+ /0.3 mol acid [1]
Do not accept aluminium hydroxide can neutralize more acid.
- 9 (a) viruses do not have cell/cellular structure
 viruses do not have nucleus
 viruses do not have cell wall
 viruses do not have cytoplasm [2]
Accept opposite statements for bacteria.
- (b) stops virus replication
Accept reproduction / multiplication.
 becomes part of DNA of virus / alters virus DNA / blocks polymerase which builds DNA
 changes the cell membrane that inhibits the entry of virus into the cells
 prevents viruses from leaving the cell (after reproducing) [2 max]
- (c) HIV mutates (rapidly)
Accept AIDS mutates
 HIV metabolism linked to that of host cell / HIV uses host cell / drugs harm host cell as well as HIV / difficult to target HIV without damaging host cell
 HIV destroys helper cells of the immune system [2 max]
- 10 (a) fast delivery / OWTTE [1]
- (b) diamorphine has (2) ester/acetyl/ COOCH_3 groups instead of hydroxyl/ OH groups
 diamorphine is less polar/non-polar [2]
- 11 if concentration is too high it will have harmful side effects / determination of the lethal dose (to 50% of the population) / OWTTE
- if concentration is too low it has little or no beneficial effect / determination of the effective dose / dose which has a noticeable effect (on 50% of the population) / OWTTE
- therapeutic window is the range between these doses / range over which a drug can be safely administered / ratio of $\text{LD}_{50}:\text{ED}_{50}$
- for minor ailments a large window is desirable, for serious conditions a smaller window may be acceptable / OWTTE
- (therapeutic window) depends on the drug/age/sex/weight
- a small therapeutic window means that an overdose is a high risk / OWTTE [4 max]
- 12 (a) amine
 ether
 alkenyl
 arene [2 max]
Allow structural representation of functional group instead of name (e.g. $\text{C}=\text{C}$ instead of alkenyl).
- (b) phenol / alcohol / hydroxyl (group) [1]
Allow OH.
- (c) (di)esterification / condensation / (di) acetylation [1]
- 13 (a) penicillins interfere with the enzymes that bacteria need to make cell walls / interfere with formation of bacterial cell walls / OWTTE
 the increased osmotic pressure causes the bacterium to die / the bacterial cells absorb too much water and burst / OWTTE [2]
- (b) resistance to penicillinase enzyme / more resistance to bacteria breaking it down / effective against bacteria that are resistant (to penicillin G)
 resistance to breakdown by stomach acid (so can be taken orally) / OWTTE [2]
- (c) amide group / $-\text{CONH}-$ / peptide
 ring is strained /
 ring breaks easily so (the two fragments similar to cysteine and valine) then bond(s)

covalently to the enzyme that synthesizes the bacterium cell wall (so blocking its action)

- 14 (a) C [3]
 (b) A / B/ A **and** B [1]
 (c) A [1]
- 15 (a) intravenous / into veins transported/pumped via blood (to various parts of the body) [2]
 (b) intramuscular/intermuscular/into muscles **and** subcutaneous/into fat [1]
 (c) inhalation/breathing it in [1]

Challenge yourself

- 1 Ethanoic anhydride is more susceptible to nucleophilic attack due to two electron-withdrawing carbonyl groups:



This enables it to react more vigorously than CH_3COOH with the $-\text{OH}$ groups in morphine.

- 2 Na_2CO_3 and NaHCO_3 contain the conjugate bases CO_3^{2-} and HCO_3^- of weak acids. They are able to hydrolyse water and release OH^- ions:
- $$\text{CO}_3^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{OH}^-(\text{aq})$$
- $$\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq}) + \text{OH}^-(\text{aq})$$
- 3 Neuraminidase inhibitors compete with the substrate sialic acid for binding to the enzyme neuraminidase. They have a chemical structure similar to the substrate and so bind in the same way at the active site of the enzyme.